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Bibliography on the Application of Reverse Osmosis to Industrial and Municipal Wastewater Research Report No. 18

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Environment Canada,
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Ontario Ministry of the Environment,
Pollution Control Branch,
135 St. Clair Avenue West,
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Bibliography on the application of reverse osmosis to industrial and municipal wastewaters / Johnston, H. Kirk.

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BIBLIOGRAPHY ON THE APPLICATION OF REVERSE OSMOSIS TO INDUSTRIAL AND MUNICIPAL WASTEWATERS

H. Kirk Johnston[1] and H. S. Lim[2]
Water and Wastewater Treatment Research Section[1]
Environmental Protection Service[2]
Environment Canada

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

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TORONTO 195, Ontario
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ABSTRACT

This review was undertaken to consolidate some of the available literature pertaining to the various applications of reverse osmosis. The period 1968-1973 (inclusive) was examined in detail.

The references herein emphasize the employment of reverse osmosis in the treatment of municipal and industrial wastewaters. Other areas of application are also included where these may prove useful in defining the limits of this separation technique. Information on related physical separation techniques such as ultrafiltration is also available in the bibliography.

The introductory portion of this report provides sufficient information on the mechanisms and applications of reverse osmosis to permit one to make a general assessment of its suitability. The physico-chemical nature of the reverse osmosis process as well as the membrane types available and their fabrication techniques are examined. An area of importance in the waste treatment field is membrane fouling and appropriate cleaning techniques are summarized for different types of surface inhibition. As different applications are most efficiently handled with appropriate equipment, the various module designs are illustrated.

RÉSUMÉ

La présente étude visait à rassembler quelques-unes des publications techniques disponibles ayant trait aux diverses applications de l'osmose inverse. Elle a porté sur la période de 1968 à 1973 inclusivement.

Les références données mettent l'accent sur l'emploi de l'osmose inverse pour le traitement des eaux usées municipales et industrielles. D'autres domaines d'application sont aussi mentionnés dans les cas où ils pourraient se révéler utiles pour définir les limites de cette technique de séparation. Dans la bibliographie, on trouve aussi de l'information sur des techniques physiques de séparation apparentées, comme l'ultra-filtration.

L'introduction du rapport donne suffisamment de renseignements sur les mécanismes et les applications de l'osmose inverse pour en permettre une évaluation générale des possibilités d'application. On y examine la nature physico-chimique du procédé de l'osmose inverse, ainsi que les types de membranes disponibles et les techniques employées pour leur fabrication. Un aspect important en matière de traitement des eaux usées est le colmatage des membranes; aussi les techniques de nettoiement sont-elles brièvement abordées pour les différents types de colmatage. Étant donné qu'une mise en application efficace nécessite l'emploi du bon matériel, on a ajouté des schémas illustrant différents types de dispositifs servant à l'osmose inverse.

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1. INTRODUCTION

The application of reverse osmosis to the treatment of industrial and municipal wastewaters is one of the many diverse areas in which reverse osmosis is being actively studied and utilized today. The concept of a semipermeable membrane separation process dates back to the exploratory studies of Reid and Breton in the late nineteen-fifties (R6). The first success in developing a suitable membrane came in 1960 from independent research under the direction of S. Sourirajan (S35) who showed that cellulose acetate membranes could be prepared with sufficient solute rejection ability and high flux characteristics to permit their utilization as a viable separation/concentration technique. Subsequent developments in the optimization of membranes from both cellulose acetate and other polymeric materials have enabled routine production of high performance membranes which can be fabricated to function efficiently in a variety of applications. Parallel advances in the design of several large scale membrane modules have permitted reverse osmosis to be effectively employed in many areas.

The most extensive employment of reverse osmosis technology has been in the desalination of brackish water and sea water. Food processing applications have also proven quite successful, particularly in whey separation but also in skim milk utilization as well as the corn, potato and orange processing industries. Concentration of industrial effluent streams for either re-use or final treatment before disposal has proven effective in such widely divergent areas as pulp and paper, organic chemicals, leather tannery wastes, fungicides, pesticides, heavy metals, paints, nuclear wastes, wash waters, and acid mine drainage. The technique has also been successful in the removal and/or concentration of most viruses and bacteria. Finally, reverse osmosis is being carefully evaluated for employment in the treatment of municipal effluent as a tertiary, secondary and even primary renovation technique.

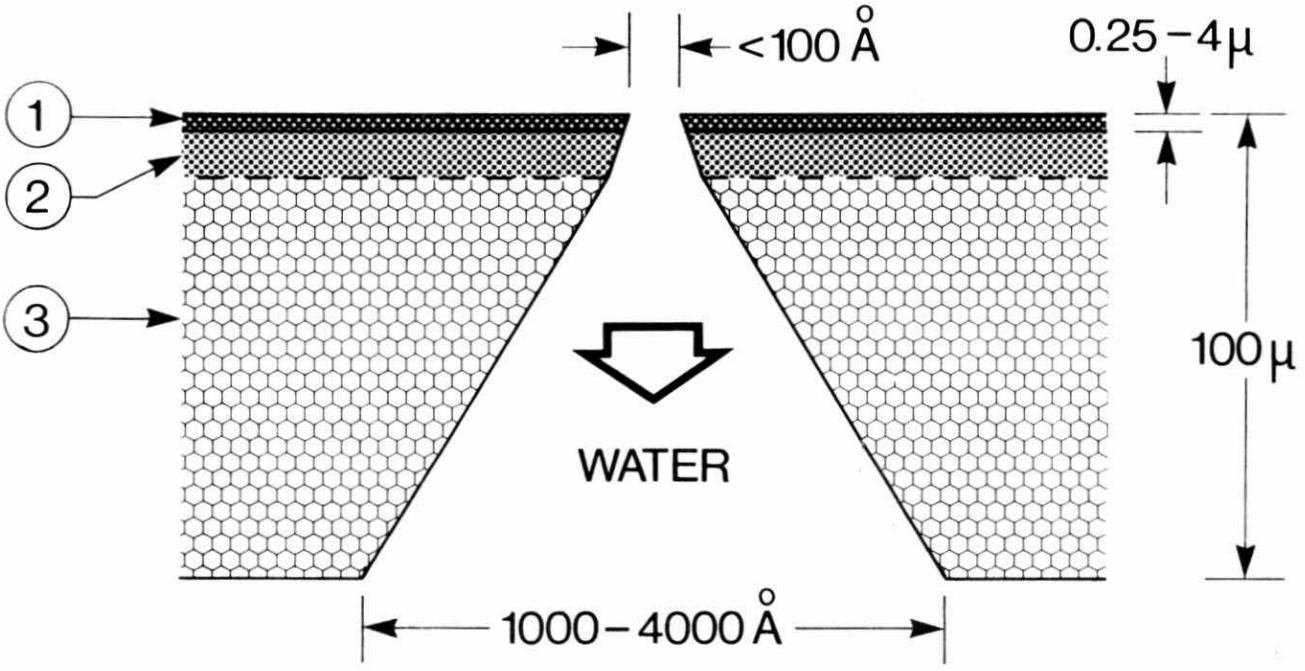
The purpose of this report is to provide a convenient summary up to the end of 1973 of much of the reverse osmosis work being carried out in the waste treatment field. Some references are supplied to other applications of reverse osmosis to permit those unfamiliar with the field to locate basic source material. The preliminary review of the general concepts of reverse osmosis is furnished for the convenience of the reader.

2. REVERSE OSMOSIS

In any system in which two solutions of differing solvent activities are separated by a semipermeable membrane, there will occur a transport of fluid through the membrane in such a manner to produce a thermodynamic equilibrium across the boundary. The pressure head that is built up above, or must be applied to, a solution to prevent the passage of fluid across the membrane is the osmotic pressure, π, and the transfer process is known as osmosis. Osmosis occurs as a consequence of the vapour pressure difference between the solutions and continues until equivalence of the free energies of the two solutions is attained. Reverse osmosis occurs when an external pressure, P, is applied in a sufficient amount to overcome existing osmotic equilibria (i.e. $P>\pi$) and cause the passage of fluid through the membrane in a direction opposite to which transfer would occur in the absence of such an external driving force. On a thermodynamic basis, both osmosis and reverse osmosis involve the transport of a fluid across a membrane in the direction of lowest chemical potential. The application of an external pressure greater than and opposite to the osmotic pressure effectively reverses the direction of fluid transport necessary to satisfy the thermodynamic requirements. Such criteria are unable to specify which component in a solution will be preferentially transported across a membrane, or to explain the mechanism whereby such transport occurs.

3. THEORIES AND MECHANISMS

The operational mechanism of reverse osmosis is generally conceded to be a physico-chemical process in which the nature of membrane-solution interactions largely determines the effectiveness of the technique for the removal/concentration of specific constituents. Ultrafiltration (U.F.), with which reverse osmosis is often compared, is essentially a physical sieving process which separates on the basis of size and shape. While such physical considerations influence the efficiency of reverse osmosis separations, surface interactions are the determining criteria for selective separations of solutes of equivalent size but different chemical natures. Operating pressures are usually significantly different between reverse osmosis and ultrafiltration, the former ranging from about 200-1500 psi and the latter usually being of the order of 100 psi or less. Such pressures are generally indicative of the macroscopic differences between these two membrane types. The sizes of ultrafiltration pores are essentially uniform throughout the membrane, and can have effective diameters that range from 200 Å to 100,000 Å. Reverse osmosis membranes, on the other hand are usually asymmetric (Figure 1), having a macroporous substructure and a dense surface layer. The substructure and the transition region function as effective supports for the dense surface layer. Although there is general agreement that this dense layer is responsible for the separation characteristics of the reverse osmosis membrane, there is still uncertainty about the structure of this surface. Some researchers claim it is uniformly dense and completely amorphous whereas others suggest it contains pores of approximately 10 Å or less. The various proposals concerning surface morphology are almost invariably supported by appropriate theories and transport equations which purport to support the various points of view. Generally speaking, the theories of transport through reverse osmosis membranes may be divided into two main groups, the pore theories and the



(1) DENSE SURFACE LAYER, 0.25 – 4 μ

(2) TRANSITION REGION, INTERMEDIATE DENSITY AND POROSITY; VARIABLE THICKNESS.

(3) SPONGY POROUS SUBSTRUCTURE

FIG. 1 ASYMMETRIC STRUCTURE OF REVERSE OSMOSIS MEMBRANE.

solution-diffusion theories, although there are many specific differences within each such group.

The originally proposed method of transport across reverse osmosis membranes was due to Reid and Breton (R6) who suggested that two distinct mechanisms occur. Water is considered to be strongly hydrogen-bonded to the carbonyl oxygens in cellulose acetate and is concentrated in the amorphous regions which predominate in such cellulosics. Consequently, ions and molecules which can combine with the membrane through hydrogen-bonding and can fit into the bound water structure can be passed across the surface by alignment of hydrogen-bonds in a diffusion controlled mechanism. Non-hydrogen-bonding species are transported by hole-type diffusion through porous regions in the cellulose acetate where there is no tightly bound water. The rates of transport by this secondary sieve mechanism depend mainly on pore size, whereas transport according to the hydrogen-bonding theory depends on the ability to fit into the ice-like membrane structure. Kesting (K10-K12) supports the concept that transport predominantly occurs by a diffusion controlled process governed by the hydrogen-bonding active site theory. Preferential membrane solubility for different compounds exerts a strong influence on such a mechanism and water transport improves when the number of hydrophobic OH sites increases in relation to the number of hydrophobic acetate ester sites. Pores are considered to be membrane imperfections which permit non-selective passage of all components of the appropriate size. Other authors also support the concept of diffusive flow through a pore-free homogeneous phase. Thau, Bloch and Kedem (T3) discounted the pore theory on the basis of the required molecular dimensions for an effective pore, although they qualify their support of the solution-diffusion mechanism with an acknowledgement that no clear distinction may be drawn between diffusion with association and capillary flow. In supporting transport by diffusive flow, Banks and Sharples (B6), suggest increased salt rejection with increase in applied pressure since the pressure effect on the

activity of a component at low concentration is small, and solvent flows increase to a greater extent at higher pressure. Yasuda et al (Y2, Y3, Y5, Y6) present a model based on the free volume concept of diffusive transport which distinguishes between transport by diffusion and bulk flow in homogeneous membranes. All of these transport theories generally characterize the passage of molecules and ions across non-porous membrane boundary layers as occurring through a "solution-diffusion" mechanism. Surface pores are regarded as membrane imperfections and transport through them is considered to be a largely non-selective phenomenon.

The other main group of theories conversely assumes that the surface of reverse osmosis membranes is inherently porous in nature and it is the number and size of these pores as well as the nature of the polymer-solution interactions which control permeability and selectivity. The most acceptable pore theory is that proposed by S. Sourirajan (S33) following his development of the first successful reverse osmosis membrane. He suggests that membrane selectivity is a surface chemistry phenomenon that is dependent on the nature of the specific interactions between the polymer surface and the various components in the solution, as generally outlined in the Gibb's Adsorption Isotherm. Transport through the porous membrane occurs by a capillary flow mechanism, wherein those components preferentially adsorbed at the interface will be transported to the greatest extent. Suitable solutions interacting with appropriate polymers enable the adsorption of a monomolecular layer of a single pure component on the membrane surface. The transport rate is a function of the number and size of the pores on the surface as well as the applied driving pressure. Selectivity is dependent on the thickness of the preferentially adsorbed layer, the size and size distribution of the pores, and the extent of interaction with the surface. This mechanism is generally referred to as the preferentially adsorption-capillary flow mechanism and it assumes all transport occurs through pores and

none occurs through solution in the polymer matrix. The general concepts of this theory have proven compatible with observed permselectivities of both organic and inorganic solutes. Glueckauf (G16, G17) proposed that the preferentially adsorbed layer is less than that suggested by Sourirajan and that the repulsion of ions occurs when solution is enclosed in a narrow pore of material of low dielectric constant. The membrane material is required only to provide suitably sized pores in a matrix of sufficiently low dielectric constant. Salt passage occurs through very large irregular pores. Meares (M37) suggested that although transport occurs predominantly by flow through tortuous channels, some also occurs by homogeneous diffusion in the polymer matrix, rejection of ions in the pores occurring as a result of electrostatic interactions. Although only 1% of the total permeation is proposed to occur by diffusion, approximately half of all solute transport is suggested to occur in this manner. Meares theory is essentially the inverse of that suggested by Kesting and by Reid and Breton. The theories of Glueckauf and Meares offer little explanation of the ability of reverse osmosis to selectively reject non-charged organic species.

Both the foregoing schools of thought, namely the solution-diffusion theory (e.g. Kesting) and the preferential adsorption-capillary flow theory (e.g. Sourirajan) have various strengths and weaknesses. As it is not possible to establish definitively the structure of the surface layer in a reverse osmosis membrane, the application of either approach is dependent on its applicability to the problems at hand and the conceptual simplicity in quantitatively resolving experimental results. Although an exact understanding of the mechanisms of reverse osmosis is not essential for a practical utilization of this process, general understanding of the possible mechanisms may enable wider application of the technique.

4. MEMBRANE PROPERTIES AND FABRICATION TECHNIQUES

Successful application of reverse osmosis requires that efficient membranes be available in suitably designed modules to permit efficient employment in a variety of applications. The optimization of membrane formulation and casting techniques and the search for new and more efficient membrane materials are areas of intensive research. Significant improvements in the performance of existing membrane materials may be achieved by careful control of relevant casting parameters such as humidity, solution temperature, environmental temperature and evaporation time (K44). Small differences in solution composition are also very important. Variation of the solvent composition by less than five percent may result in a reduction in solute rejection of up to thirty times (Johnston, J14) and the type and concentration of the swelling agents employed can cause major differences in membrane performance. Most of these characteristics have been demonstrated in detail for cellulose acetate which is the most explicitly characterized membrane material.

The search for alternate membrane materials has been extensive (Horowitz, H39), but because of the necessity to optimize both the casting solution composition and the casting conditions in order to assess each new polymer adequately, such research is necessarily complex. Several new membrane materials have emerged, the most notable of which is the aromatic polyamide produced by DuPont. A more recent development is an inorganic ultrafiltration membrane (Union Carbide) which may potentially be adapted for reverse osmosis applications. However, the membrane material which produces the highest flux per unit of surface area and has the greatest salt rejection ability is still cellulose acetate.

Although cellulose acetate has excellent permeability characteristics, it is nonetheless limited in certain applications because of its lack of chemical resistivity. The ester groups

tent to undergo hydrolysis in solutions where the pH exceeds 8 or is below 3.5, thereby causing an irreversible reduction in membrane performance. Aromatic polyamide membranes are capable of efficient operation in slightly more basic situations (pH 5 to 11). A material capable of practical utilization over the entire pH range has not yet been developed. Consequently, existing membranes are sometimes employed under conditions in which their practical lifetime is severely limited (Golomb, G28-G30). Even under such non-ideal operating conditions, the process often proves economically advantageous. Both the cellulose acetate and aromatic polyamide membranes must remain moist in order to function efficiently under usual reverse osmosis applications. Recent applications of membrane separation techniques to such areas as helium recovery from natural gas (Habgood, H1) have indicated a need for dry membranes. This has been accomplished with cellulose acetate both by drying existing membranes (Martin, U.S. Patent 3373056) and by modifying casting formulations and techniques to permit the initial formation of dry membranes which may subsequently be repeatedly wetted and dried without adverse effects on their performance (Kesting, K11). Rather than drying the polyamide films, an alternative membrane material has been developed for gas phase separations although at low permeabilities.

Basic differences between the two main membrane-forming polymers have necessitated different fabrication techniques to optimize their reverse osmosis performance. Cellulose acetate films and fibres may be composed of individual polymers or mixtures of polymers in which the acetyl contents may range between approximately 38% and 43%. Molecular weights can vary between about 25,000 and 65,000. Membranes are prepared from a solution consisting of the polymer dissolved in an appropriate solvent (usually acetone) along with a non-solvent (water or formaldehyde) and an appropriate salt, both of which function as swelling agents. Membranes may be cast in sheet or tubular form by physically spreading a desired thickness of this solution

on an appropriate support under controlled atmospheric conditions Evaporation is allowed to take place for a controlled period of time to permit solvent diffusion through the polymer and from the surface; this results in the characteristic membrane asymmetry. This structure is gelled by immersing the film in a bath of water maintained near freezing. The cellulosic membranes in this "as-cast" condition are generally "macroporous" and show little solute rejection. By heating the membrane in a water bath at an appropriate temperature, the cellulosic material becomes partially crystalline and the resulting polymer shrinkage reduces the size of the pores throughout the film, thereby causing higher solute rejection although at lower permeation rates.

Aromatic polyamide hollow fibres are prepared from a casting dope of the polymer in dimethyl acetamide. The dope is extruded through a sealed, vented insert-spinneret which permits a flow of inert gas into the centre of the filament, thereby maintaining the central bore during fibre setting. Solvent evaporation from the surface (and through the fibre toward the outer surface) occurs at a controlled rate as the filaments pass through a heated cell on emerging from the spinneret. This produces an assymmetric fibre with a dense outer surface and a more porous inner support. The polymer structure is frozen in a quenching bath of water which also serves to leach out extraneous solvent. The fibres are then wound (wet) onto bobbins prior to wrapping the membrane core unit for a completed permeator.

The polyamide used in this process is more resistant to basic solutions than is cellulose acetate, and can operate within the wider pH range of 4 to 11. However, extended usage at more extreme pH's causes irreversible modification of the membrane material and alters its separation characteristics.

5. MODULE CONFIGURATIONS

Once a membrane material has been chosen for a specific reverse osmosis application, the selection of the most appropriate membrane configuration is often critical to the success of the process. Membranes are contained in modules of various designs, the capacity of which can range from a few millilitres per hour to millions of gallons per day. The ability to choose from several module designs permits optimum employment of this separation technique and is partially responsible for the increased utilization of reverse osmosis in recent years. Table I summarizes the membrane and module designs available for cellulose acetate and aromatic polyamides. The addresses of the manufacturers and distributers of appropriate equipment shown in Table I are presented in Appendix I.

There are basically four main types of module designs available: plate and frame, spiral wound, tubular, and hollow fibre. Each design has its specific merits and can consequently achieve optimum efficiency under different conditions of operation. Some general characteristics are described below.

5.1 Plate and Frame

The plate and frame configuration was the first design employed in large scale applications of reverse osmosis membrane technology. Developed by the Aerojet-General Corporation, the units consist of membranes supported on porous plates and arranged one on top of the other (Figure 2). Two different flow configurations may be utilized, one in which the permeated water is collected at the outer edge of the "stack" and the other in which a central collection tube is employed. Turbulence promoting devices adjacent to the membrane-solution interfaces improve transport characteristics and reduce surface fouling to a certain extent.

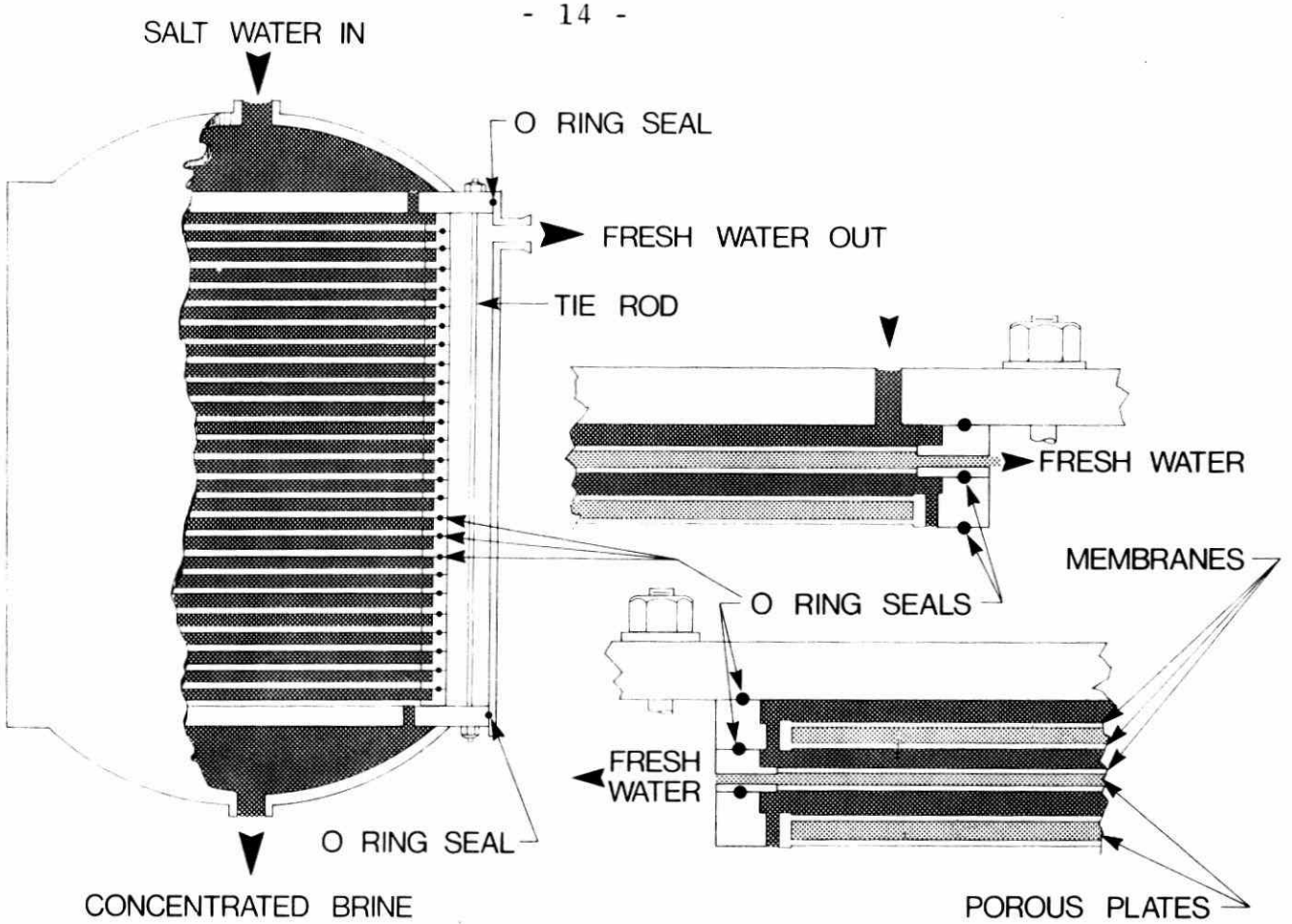
TABLE I

REVERSE OSMOSIS MODULE DESIGNS AND MEMBRANE CONFIGURATIONS

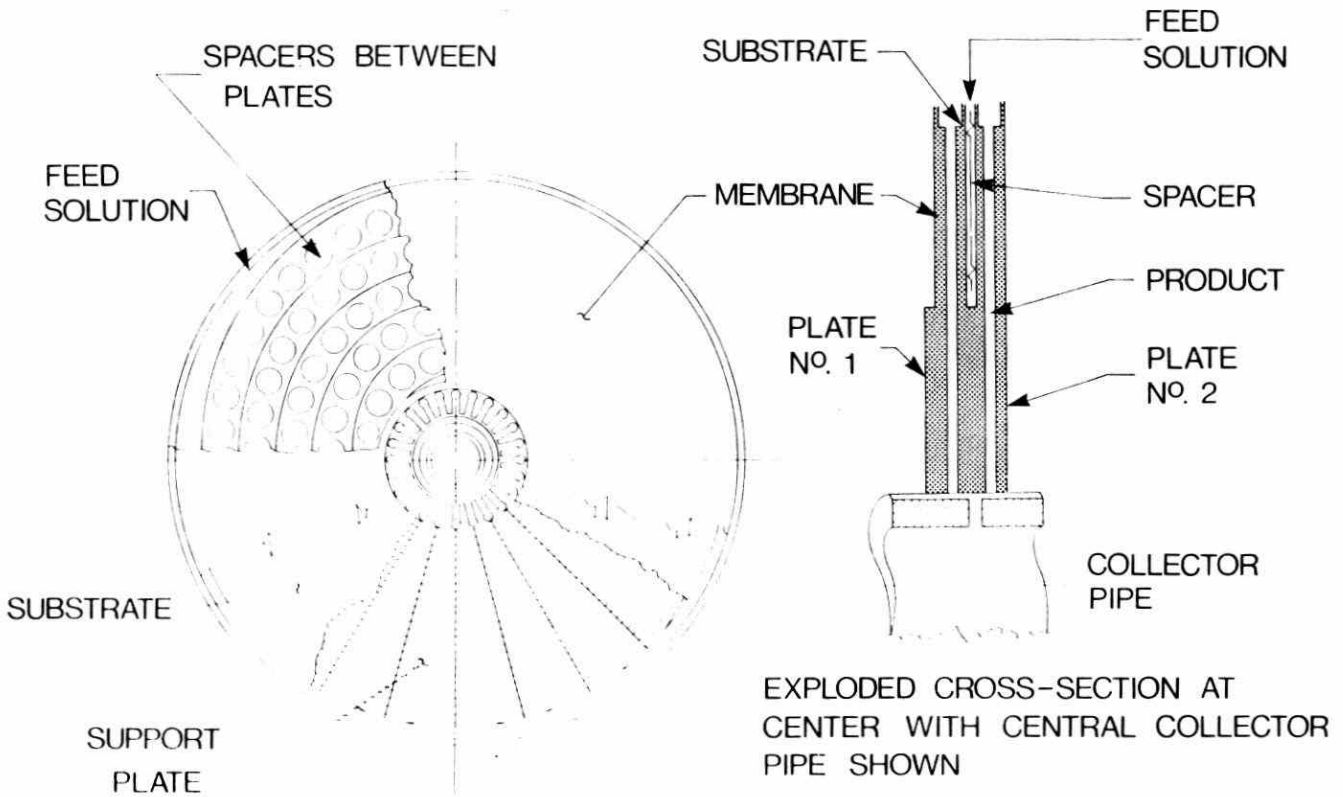
MEMBRANE CONFIGURATION	MODULE DESIGN	POLYMER MATERIAL	MEMBRANE MANUFACTURERS	MODULE MANUFACTURERS & DISTRIBUTERS
Flat	Plate & Frame*	Cellulose Acetate[1]	Envirogenics	Amicon
		Aromatic Polyamide[2]	DuPont	Gulf
		Inorganic	Union Carbide	Union Carbide
	Spiral Wound	Cellulose Acetate	Gulf General Atomic	Gulf/Ajax/Desalination/ Envirogenics
Tubular	External Tube	Cellulose Acetate	Raypak	Raypak
		Cellulose Acetate	Universal Water Corporation	Universal Water Corporation
	Internal Tube	Cellulose Acetate	Universal Oil Products	Universal Oil Products/ Abcor
		Cellulose Acetate	Westinghouse	
		Cellulose Acetate	Electrohome	
		Cellulose Acetate	Philco Ford	
		Cellulose Acetate	American Standard	Aqua Chem
Hollow Fibre		Aromatic Polyamide	DuPont	DuPont de Nemours
		Acrylic	Biomed	
		Cellulose/Cellulose Acetate/Silicone poly-carbonate	Dow	Dow/Biorad
		Non-cellulosic	Amicon	Amicon/Mandel Scientific

1. Usable pH range 3.5 - 8.0
2. Usable pH range 4.0 - 11.0

* No plate and frame large scale modules are currently manufactured for reverse osmosis units; this type of configuration is a suitable general design for preliminary testing of new membrane materials. Suitable test cells are made by Amicon and used by Dow Chemical for ultrafiltration.



TYPE I DESIGN WITH OUTSIDE COLLECTOR TUBES



TYPE II DESIGN WITH CENTRAL COLLECTOR PIPE

Eastman Chemical Products, Inc.

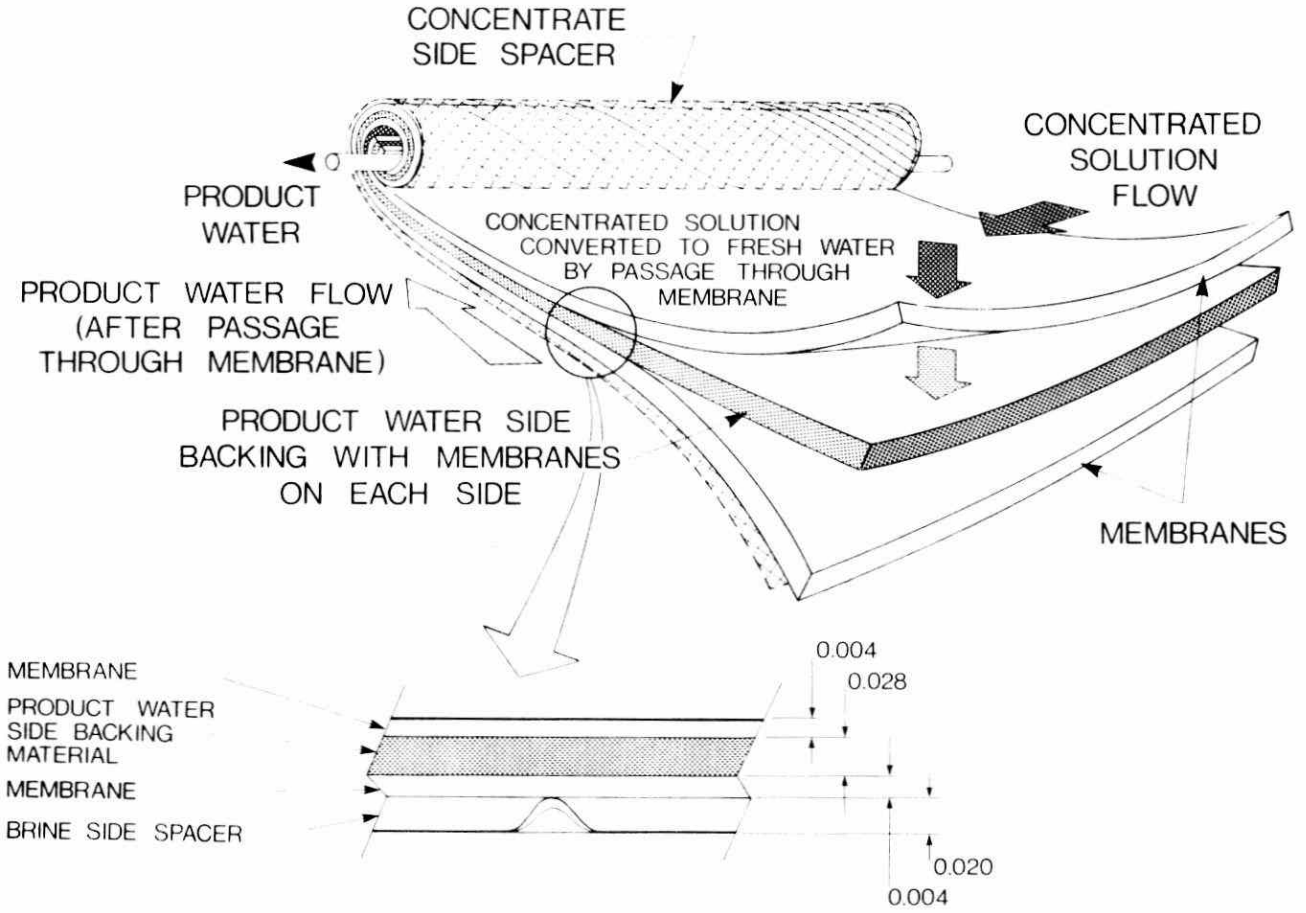
FIG. 2 PLATE AND FRAME REVERSE OSMOSIS UNITS

A limited number of these units were assembled for large scale applications and certain deficiencies became apparent. Because of the requirement for mounting each membrane on an individual supporting device and the necessity of stacking these devices, the required equipment and maintenance costs are excessive in comparison to the productivity obtainable from such an arrangement. The tendency of the membrane surfaces to foul in the narrow separating channels, the large space requirements, and the difficulty of replacing damaged membranes combined to reduce the practicality of the plate and frame configuration. Nonetheless, the units employed in various applications demonstrated that reverse osmosis could be applied to certain large scale processes.

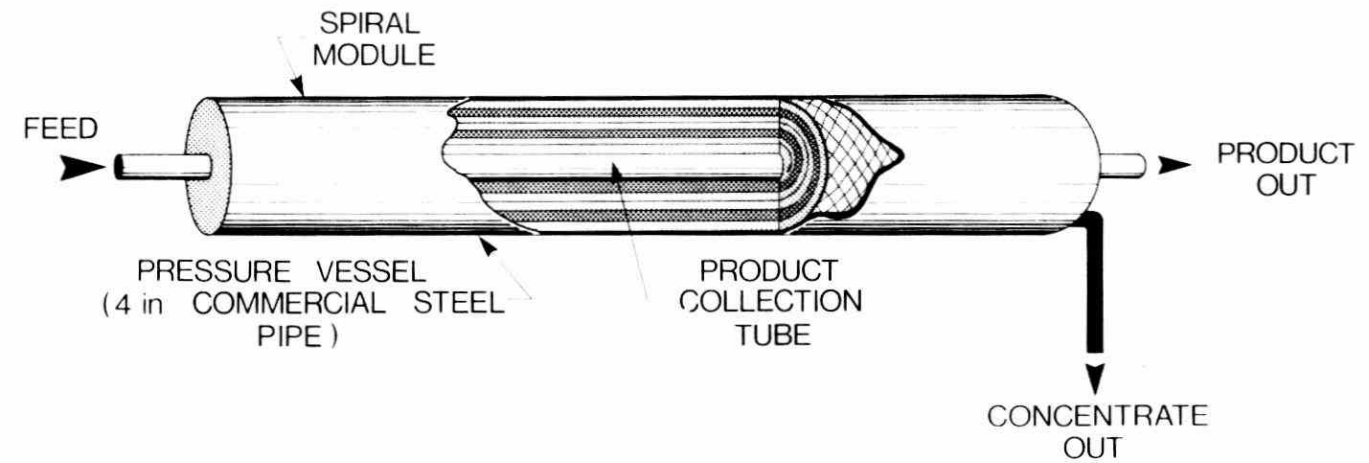
5.2 Spiral Wound

To overcome some of the equipment problems encountered in the plate and frame design, a spiral wound module was developed (Figure 3). The spiral wound configuration consists basically of two large, flat membranes separated by a flexible porous support and wrapped around themselves to form a jelly roll-like structure. The edges of the membrane unit are sealed and the flow of the feed/concentrate solution is directed axially through the roll, thereby encountering the entire surface area before passing out the spacer ports at the end. Permeate passes between the paired membrane layers toward a porous collection pipe at the centre of the wound module. An external tubular pressure container encases the membrane core unit.

This configuration enables maximum membrane film area to be housed in the minimum possible space. Several modules can be arranged in either series or parallel to achieve the desired level of separation and recovery. The restricted nature of the long flow path, however, causes rather substantial pressure drops which may necessitate the use of auxiliary pumps in large scale applications. The proximity of the membrane



SPIRAL-WOUND MEMBRANE MODULE, PARTIALLY UNROLLED.



SCHEMATIC OF SPIRAL-WOUND MEMBRANE MODULE

Gulf General Atomic

FIG. 3 SPIRAL-WOUND REVERSE OSMOSIS MODULE

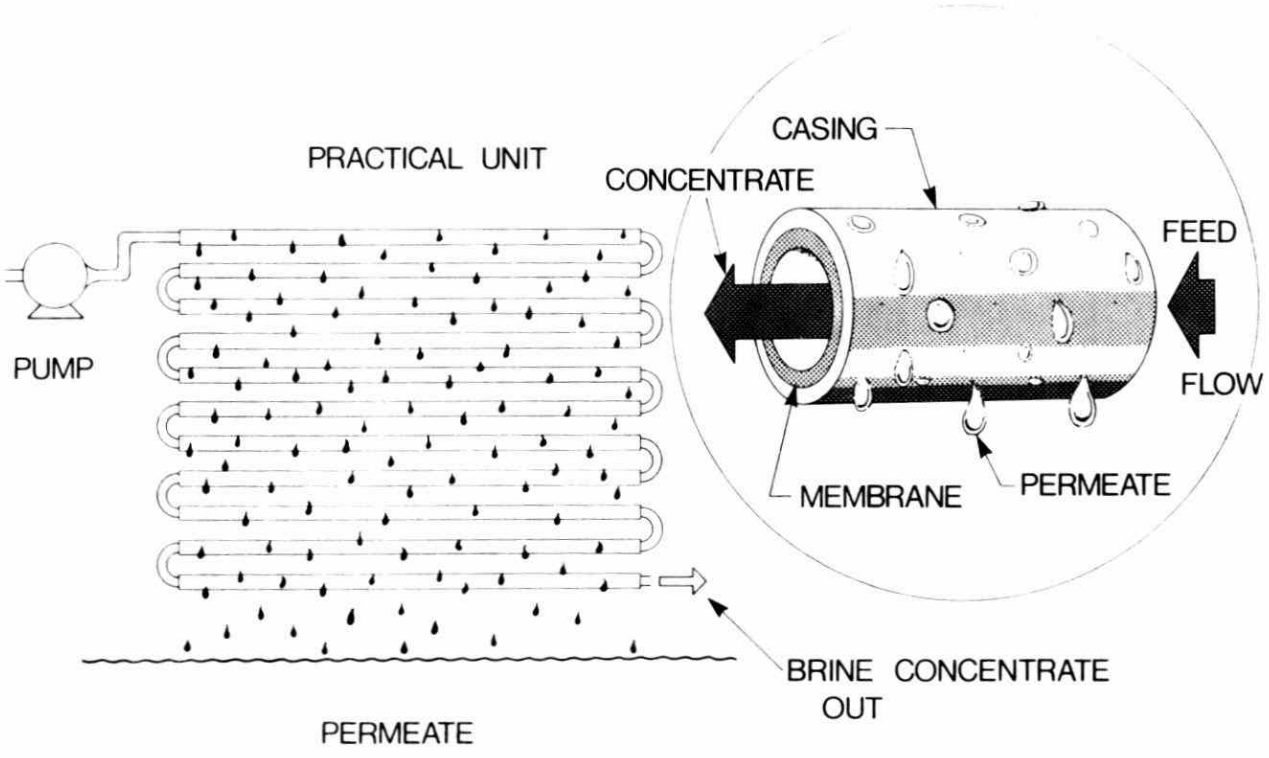
surfaces to each other results in easy membrane fouling and plugging of the narrow interfacial flow channels. Because the surface turbulence is comparable to the plate and frame design, the treatment of viscous fluids or fluids with high solids content is not optimally handled by the spiral wound module.

5.3 Tubular

Modules of the tubular configuration are the most amenable to treatment of viscous liquids. Tubular membranes may be either internally or externally supported (Figure 4) and turbulence promotors can be easily employed with certain designs when required. The ability to adjust flow characteristics through the tubes permits efficient treatment of viscous solutions and reduces surface fouling. Minimum pre-treatment is necessary when using such modules and when required, cleaning by most of the available techniques is readily accomplished. The necessary membrane supports, permeate collection and transfer tubes, module encasing and connecting devices and the small membrane area per module make the tubular arrangement the most expensive to fabricate and install and yield the lowest permeability per unit volume of equipment.

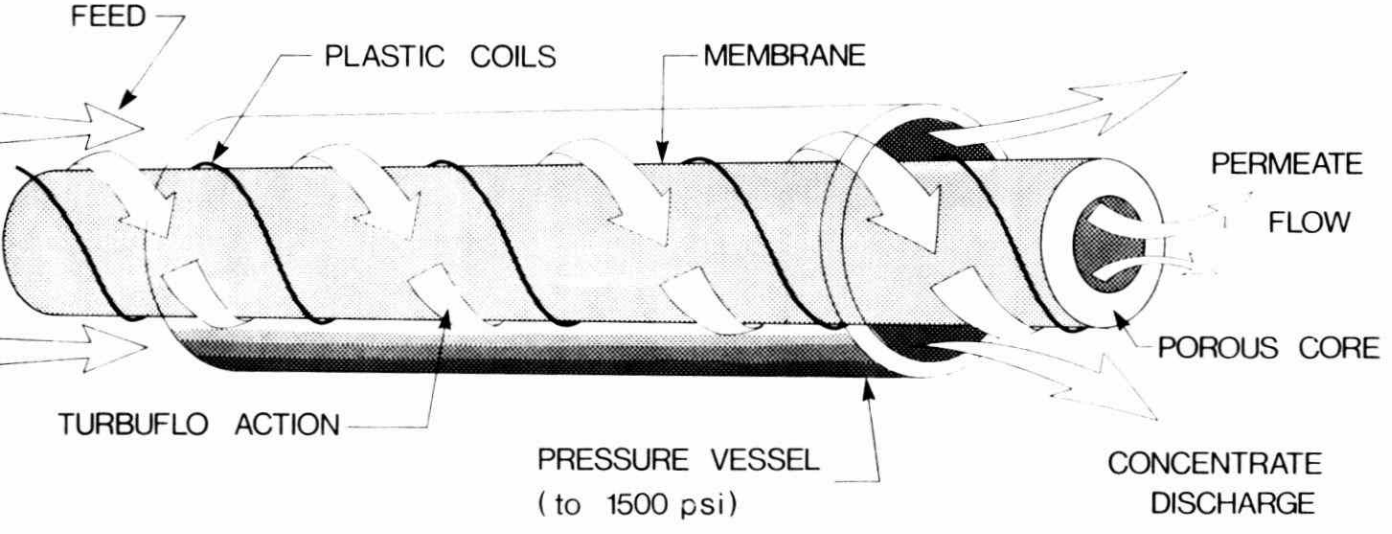
5.4 Hollow Fibre

The hollow fibre design permits maximum membrane area per unit equipment volume. The membranes are spun in the form of hollow fibres, the thickness of which is similar to a human hair (85-200 μ O.D.). These are wrapped around a support frame and the open ends of the looped fibres are potted in a resin matrix. This fibre bundle is encased in a cylindrical container into which the feed solution is pumped under pressure. Permeate is passed through the inside of the hollow fibres to be collected at the open ends encased in the resin (Figure 5).



TYPE I DESIGN WITH MEMBRANE EXTERNALLY SUPPORTED

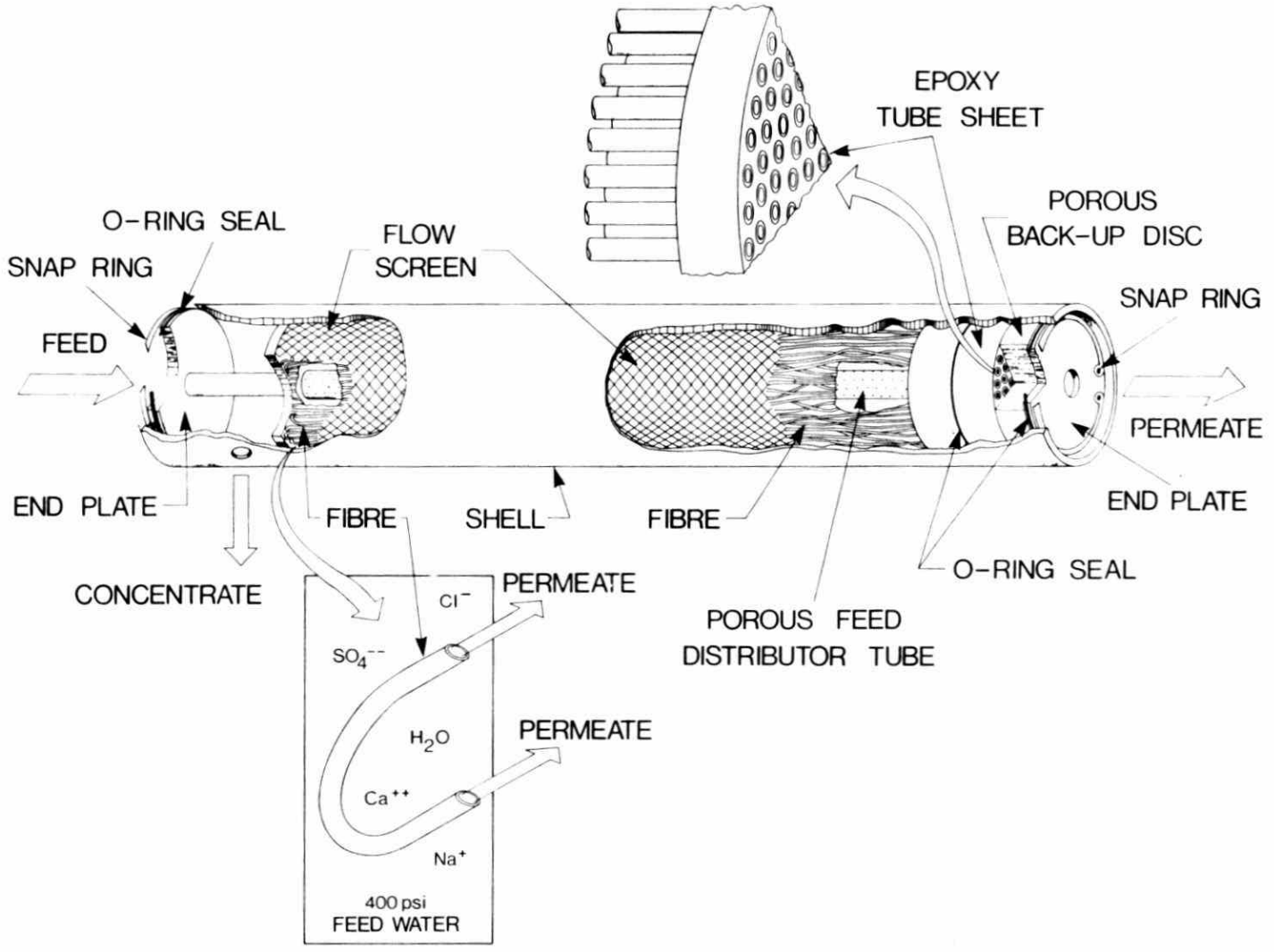
Eastman Chemical Products, Inc.



TYPE II DESIGN WITH MEMBRANE INTERNALLY SUPPORTED

Raypak, Inc.

FIG. 4 TUBULAR REVERSE OSMOSIS



COMMERCIAL PERMEATOR, CUTAWAY DRAWING
Du Pont de Nemours and Co.

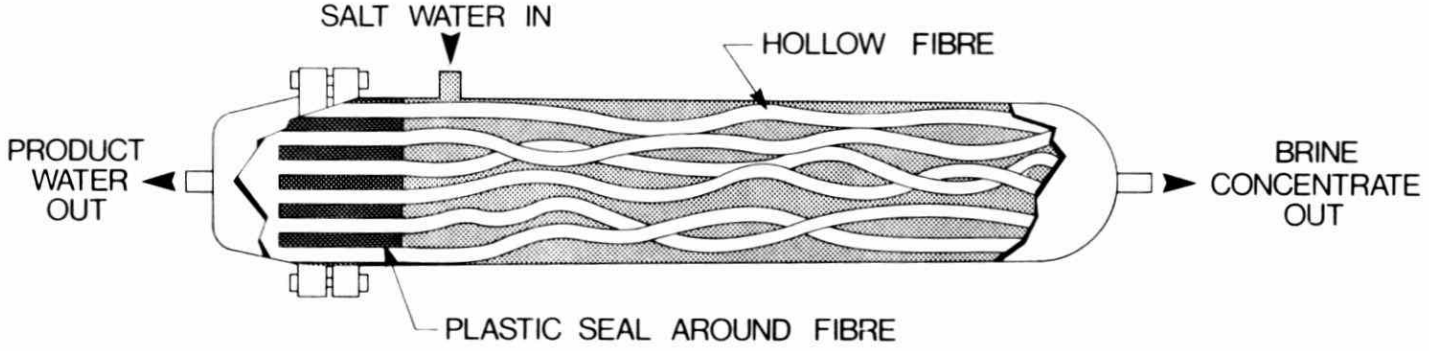


ILLUSTRATION OF HOLLOW FIBRE REVERSE OSMOSIS PROCESS.

FIG. 5 HOLLOW FIBRE REVERSE OSMOSIS MODULE

The main advantage of this configuration is the exceptionally high membrane surface area that is available in very small modules. Although some of the membrane materials are not especially permeable (e.g. aromatic polyamide) on a per unit membrane area basis, the basic membrane density in the fibre-containing modules still results in high capacity units. As the fibres themselves are capable of withstanding the pressures applied, the encasing module is the major mechanical component of the complete unit and no support screens are required. This results in comparatively low equipment costs. Fluids with suspended solids or high viscosities are not usually treated with these modules because of their tendency to foul very easily and the difficulty of adequately cleaning the fibrous surfaces. Pretreatment processes may be employed to render the feed solutions suitable for treatment in such a system. Demineralization of brackish waters and treatment of impure household waters proved to be areas of optimum employment for this module design.

6. MEMBRANE CLEANING TECHNIQUES

In the operation of reverse osmosis units, permeate flux tends to decline as a consequence of fouling of the membrane surface, densification of the polymer substructure due to applied pressures, and irreversible chemical and/or physical damage to the polymer surface layer. In the latter case, hydrolysis of the ester group in a cellulose acetate membrane or physical abrasion of the surface by particulate materials in the feed solution are relevant examples. Surface fouling by colloidal gels or solid precipitates increases the effective osmotic pressure of the feed, thereby reducing the net driving force of the reverse osmosis process. This, in conjunction with reduced permeability due to physical flow restrictions imposed by the adsorbed materials, is one of the major difficulties which must be overcome to successfully apply reverse osmosis to the treatment of various industrial and municipal wastewaters.

In order to justify the use of reverse osmosis in many applications, surface fouling must be easily overcome, either through the development of non-fouling membrane materials or through the optimization of effective cleaning techniques. Membrane fouling depends on feedwater quality, extent of pretreatment, and the degree of surface turbulence. Five general types of membrane fouling and related problems are summarized below, along with the most appropriate counter measures presently available.

6.1 Membrane Densification and Loose Foulants

(a) Periodical shut down of the unit for several minutes enables the membrane to "relax".

(b) Flush the membrane at twice the normal velocity with feed solution or tap water at reduced pressure.

(c) Air may be introduced into the system to help loosen the foulants during the flushing.

6.2 Hardness Scales

(a) These are precipitates of calcium and magnesium carbonates and sulfates and can be avoided by keeping the water recovery low (<50%), by adding antiscale solutions such as sodium hexametaphosphate, and by controlling the pH of the solution in the acidic range where precipitation will not occur.

(b) Carbonate scale may resist mechanical flushing but can be dissolved in acid solution. Conversely, calcium sulfate scale is more readily removed by flushing but is less easily dissolved than carbonate.

(c) A warm, weak acid solution (e.g. 1-2% citric acid) or solution of ammonia citrate may be used to remove the scales.

(d) Periodic addition of small amounts of citric acid into the feed help prevent the accummulation of inorganic surface foulants.

(e) The sodium salt of an EDTA solution has also been suggested for $CaSO_4$ scale removal.

6.3 Iron Oxides and Aluminum Silicates

(a) The treatment and prevention methods are similar to those for hardness scales.

(b) Stronger acids such as HCl in tap water at a pH of about 3 can be circulated through the system for short periods.

6.4 Adsorbed Organics

(a) Fouling by adsorbed organics is sometimes sufficiently weak that circulation of clean water through the system may be adequate to restore membrane performance. However, it is generally necessary to clean the membranes on a regular basis.

(b) Enzyme cleaning is so far the most effective method. An enzyme detergent solution such as Biz, Tergazyme, or Bold at proper concentration and pH is initially circulated vigorously through the system and then the membrane is soaked in the solution for a period of time.

(c) Some organic colloids or proteins could be dissolved by employing pH adjusted water.

6.5 Microbiological Growths

(a) Small amounts of biocide can be introduced into the feed stream or the feed may be presterilized using chlorine or ozone. Free chlorine may damage some membranes, especially the polyamide type.

(b) Methods of cleaning are similar to those employed in treating organic foulings.

(c) Circulation of a solution of sodium hypochlorite through the system for about thirty minutes has also been suggested to sterilize the system.

A physical cleaning method may further be employed in tubular systems. In such a technique, sponge balls with a diameter at least equal to the inside diameter of the tube are pushed through the tube by the applied pressure and are physically able to scrape off precipitants and foulants on the membrane surface as they pass through the system.

7. APPLICATION OF REVERSE OSMOSIS TO WASTEWATER TREATMENT

Reverse osmosis is an effective separation/concentration technique for a wide variety of both organic and inorganic species. It has consequently proved appropriate for the treatment of many industrial and municipal wastes. The more successful employment of reverse osmosis technology has so far been in the area of industrial waste control. This is in part due to the fact that the industrial waste streams are more concentrated and have limited variability in their composition. Appropriate pre-treatment and post-treatment can be more conveniently designed for such systems and disposal/reuse of the concentrate optimized. Successful reuse of waste materials has sufficient merit in some situations to make this treatment process economically advantageous. Reclamation of metals from plating wastes and of whey from cheese processing plants are two examples in which either reuse or the sale and redirection of concentrated components has provided economic impetus to the installation of reverse osmosis units. Other areas in which concentrated wastes can be reused include dilute latex paint and some organic chemical wastes. Various food processing effluents have been successfully treated. Wash water from bean, corn and potato processing operations has been treated, largely to reduce excessively high B.O.D. loadings that result from such industries. Some processing plants can economically employ reverse osmosis as a pre-concentration step in the manufacturing sequence and thereby reduce excessive power costs required for freeze drying (coffee) or evaporation (fruit and vegetable juice) units. Also, petrochemical and leather tannery wastes as well as acid mine drainage can be treated to remove high B.O.D. or toxic materials in order to achieve legislated pollution guidelines. Initial acceptance of reverse osmosis as a method of treating industrial effluents was slow, but many recent practical and economic successes have encouraged rapid development in reverse osmosis for the waste control field (e.g. G30).

Development of higher capacity more efficient modules has prompted several studies to evaluate the efficiency of reverse osmosis as a primary, secondary or tertiary treatment technique for municipal effluent. The ability to remove essentially all virus and bacteria as well as most inorganic and organic species in both dissolved and suspended form suggests this technique may be ideally designed for such effluent treatment. However, high equipment and operational costs, the tendency of the membrane surface to foul, and their susceptibility to shock loadings, as well as the uncertain operational lifetime of the membranes under extreme usage have all been initially cited as major difficulties to be overcome. Reliable data from pilot and full scale test units in this area is rather sparse at present and numerous tests are presently underway. Preliminary results in several areas are encouraging and it appears possible that successful incorporation of reverse osmosis in an advanced municipal waste treatment system may be soon forthcoming.

BIBLIOGRAPHY

A1 Abron, L.A., and J.O. Osburn, "Transport mechanism in hollow nylon fibre reverse osmosis membranes for the removal of DDT and aldrin from water", Water Research, 7(3), 461-477 (1973).

A2 Abron, L.A., "Transport mechanism in hollow nylon fibre reverse osmosis membranes for the removal of DDT and aldrin from water", Thes. Eng., University of Iowa, Iowa (1972).

A3 Agardy, F.J., and H. Daubert, "Improving municipal water supplies in Colorado by desalting", U.S. Office Saline Water, Res. Develop. Progr. Rep. 1971, No. 702, 114 pp.

A4 Agrawal, J.P. and S. Sourirajan, "Reverse Osmosis", Ind. and Eng. Chem., 6(11), 62(1969).

A5 Agrawal, J.P. and S. Sourirajan, "Specification, selectivity, and performance of porous cellulose acetate membranes in reverse osmosis", Ind. and Eng. Chem., Porcess Design and Development, 8(4), 439-449 (1969).

A6 Agrawal, J.P. and S. Sourirajan, "High flux, freeze-dried cellulose acetate reverse osmosis membranes as microporous barriers in gas permeation and separation", J. Appl. Poly. Sci., 14(50), 1303-21 (1970).

A7 Agrawal, J.P. and S. Sourirajan, "Reverse osmosis separation of some inorganic salts in solution containing mixed solutes with a common ion", Industrial Engineering Chemistry, Process Design and Development, 9(1), (1970).

A8 Ahlgren, R., "Electromembrane processing of cheese whey", Chapter IV in "Industrial Processing with Membranes", R. Lacey, and S. Loeb, editors, Wiley, New York (1972).

A9 Ahlgren, R., "Electromembrane processes for recovery of constituents from pulping liquors", Chapter V in "Industrial Processing with Membranes", R. Lacey and S. Loeb, editors, Wiley, New York (1972).

A10 Alfani, F. and E. Drioli, "Concentration polarization in an unstirred batch system", Quad, Ing. Chim. Ital., 8(11), 234-40 (1972).

A11 Ammerlaan, A.C.F. and A.J. Wiley, "The engineering evaluation of reverse osmosis as a method of processing spent liquors of the pulp and paper industry", Chem. Eng. Prog. Symp. Series, 65(97), 26-31 (1969).

A12 Ammerlaan, A.C.F., B.F. Lufck and A.J. Wiley, "Membrane processing of dilute pulping wastes by reverse osmosis", TAPPI, 52(1), 118 (1969).

A13 Anderson, J.E., S.J. Hoffman and C.R. Peters, "Factors influencing reverse osmosis rejection of organic solutes from aqueous solution", J. Phys. Chem., 76(26), 4006-11 (1972).

A14 Anderson, J.R. and R.S. Hamilton, "The impact of reverse osmosis and progressive mode ion exchange on water pollution", AIChE Symposium Series, 68(124), 349-55 (1972).

A15 Applegate, L.E. and R.C. Antonson, "Phenomenological characterization of DP-1 membranes", Reverse Osmosis Membranes Res., 243-52 (1972).

A16 Aurich, C. et al "Treatment of textile dyeing wastes on dynamically formed membranes", Water Pollution Control Federation, Washington, D.C. Journal, 44(8), 1545-551 (1972).

AN1 Anonymous, "A state of the art review of metal finishing waste treatment", Water Poll. Cont. Res. Ser. No. 12010 EIE 11/68, EPA·WQO, U.S.(1968).

AN2 Anonymous, "A widely hailed water-desalting technique looks good for maple syrup too", Chemical Engineering, October 7 (1968).

AN3 Anonymous, "An investigation of techniques for removal of chromium from electroplating wastes", Battelle Memorial Institute, U.S. E.P.A. report 12010EIE March (1971).

AN4 Anonymous, "Acid mine waste treatment using reverse osmosis", Water Pollut. Control Res. Series 14010 DYG 11/70 EPA·WQO, U.S. (1970).

AN5 Anonymous, "Application of Hyperfiltration to treatment of municipal sewage effluents", Water Poll. Cont. Res. Series ORD-17030 EOH 01/70, U.S. Dept. of the Int., FWQA, (1970).

AN6 Anonymous, "Bibliography", Amicon Corporation Publication No. 428, (1972).

AN7 Anonymous, "Clean water through plastics", Modern Plastics, July (1969).

AN8 Anonymous, "Combined steel mill and municipal wastewaters treatment", Weirton Steel Division, National Steel Corp., U.S. Environmental Protection Agency Report no. 12010DTQ o2/72. NTIS PB 210 198.

AN9 Anonymous, "Dorr-Oliver IOPOR system for electropainting", Ultrafiltration Systems to Reduce Your Electro-painting Costs, Bulletin No. 10-2, (1970).

AN10 Anonymous, "Eastman* membrane for reverse osmosis", Eastman Kodak Chemical Products, Inc., Technical Bulletin TBM-1A, TBM-2, PM-4, PM-5.

AN11 Anonymous, "Economic analysis of industrial waste treatment using Calgon-Havens reverse osmosis", Engineering report (1972).

AN12 Anonymous, "Electrodialysis in advanced waste treatment", U.S. Dept. of the Interior, FWQA, Publ. No. WP-20-AWTR-18.

AN13 Anonymous, "Electrodialysis of spent pickle liquor and recovery of magnetic iron oxides", Industrial Water Engrg., 7(3), 38 (1970).

AN14 Anonymous, "Enro-spiral wrap system of reverse osmosis water treatment", Envirogenics Company, Trade Literature, Un-numbered, May (1972).

AN15 Anonymous, "Gama rays fix permeability of treated membranes", E & EN, 18 May (1970).

AN16 Anonymous, "High-yield thin-channel (TC*) filtration system TCID", Data Sheet No. 1009, April (1971).

AN17 Anonymous, "Hollow fiber use in water treatment expands", Chemical and Engineering News, 49(23), 29 (1971).

AN18 Anonymous, "In a clean sweep ultrafiltration turns loss to profit", Engineer (London), 231(5978), 26-27 (1970).

AN19 Anonymous, "Industrial waste processing with reverse osmosis" Technical Bulletin, Osmonics, Inc.

AN20 Anonymous, "Improved reverse osmosis membrane", Mech. Eng., 92(3), 42 (1970).

AN21 Anonymous, "It's full speed ahead for reverse osmosis", Chemical Week, 3 August (1968) 40-41.

AN22 Anonymous, "Latest membrane developments spur reverse osmosis interests", Ind. Water Eng., 6(2), 6-8 (1969).

AN23 Anonymous, "Mathematical model of electrodialysis process", Water Pollut. Cont. Res. Series 17090 FTA 07/69, EPA·WQO, U.S. (1969).

AN24 Anonymous, "Membrane processing of cottage cheese whey for pollution abatement", Water Pollution Control Research Series, July (1971), Crowley's Milk Co., Binghamton, New York, 118 W72-09385, EPA-12060-DXF-07/71.

AN25 Anonymous, "Membrane Science and Technology", Symposium on Membrane Science and Technology: Ind., Biological and Waste Treatment Processes, Columbus Ohio, (1969), Flinn, J.E. (Ed.), Plenum Press, N.Y. (1970).

AN26 Anonymous, "Membrane use aided at industrial waste water", Chemical and Engineering News, 27 Sept. (1971).

AN27 Anonymous, "New ultrafiltration system uses inorganics", Chemical and Engineering News, 28 Jan. (1974) 24, 25.

AN28 Anonymous, "New and ultrathin membranes for municipal wastewater treatment by reverse osmosis", North Star Research and Development Institute, Water Pollut. Cont. Res. Series 17020 EFA 10/70, EPA·WQO, U.S. (1970).

AN29 Anonymous, "One answer to water supply and purity problems may be reverse osmosis", The Future Markets, 15 January (1972).

AN30 Anonymous, "Osmosis membrane", Industrial Research, 34, August (1967).

AN31 Anonymous, "Osmotik* processes for the dairy industry", Bulletin No. 24-1, Calgon-Havens Systems, Calgon Corp., Pittsburgh, undated.

AN32 Anonymous, "Osmotik* process sytems for pollution control and by-product recovery in the pulp and paper industry", Bulletin no. 24-2, Calgon Havens Systems, undated.

AN33 Anonymous, "Osmotik* test systems" Bulletin no. 24-3, Calgon-Havens Systems, undated.

AN34 Anonymous, "Osmotik* pilot processor", Bulletin no. 24-5, Calgon-Havens Systems, undated.

AN35 Anonymous, "Paper makers evaluate portable reverse osmosis unit", Environ. Sci. & Technol., 3, 203 (1969).

AN36 Anonymous, "Permasep* permeator", duPont Technical Bulletin, 100A, 105 and 110 (1972).

AN37 Anonymous, "Removing nitrates from water", J. of Agricultural and Food Chemistry, 18(5), 785-88 (1970).

AN38 Anonymous, "Reverse osmosis: A profile", Industrial Water Engineering, 10(3), 16-25 (1973).

AN39 Anonymous, "Reverse osmosis: An old concept in new hardware", Ind. Water Eng., 4, 20 (1967).

AN40 Anonymous, "Reverse osmosis for wastewater treatment", Gulf General Atomic Inc., San Diego, Calif., Report no. GA-8020, (1967).

AN41 Anonymous, "Reverse osmosis for municipal water supply", C.P. Shields, Technical Bulletin, duPont (1971).

AN42 Anonymous, "Reverse osmosis is key to spot-free rinsing of anodized parts", Ind. Finishing 48, 30-2, July (1972).

AN43 Anonymous, "Reverse osmosis makes purified water economically and ecologically", Environmental Design, 11(3), 25, Fall (1971).

AN44 Anonymous, "Reverse osmosis may solve whey disposal problem", Agricultural Research, 16(11), 13 (1968).

AN45 Anonymous, "Reverse osmosis may be the answer to whey disposal", Environmental Science and Technology, p.490 (1968).

AN46 Anonymous, "Reverse osmosis may help pulp mills cut pollution three ways", Chemical Week, Jan 27 (1968) and Chemical and Engineering News, Jan 22 (1968) p. 39.

AN47 Anonymous, "Reverse osmosis module operates below 450 psi", Chem. Eng., 78(9), 72 (1971).

AN48 Anonymous, "Reverse osmosis purifies brackish well water", Ground Water Age, 6(7) 22 (1972).

AN49 Anonymous, "Reverse osmosis renovation of primary sewage", Pub. Works, 103, 102+, July (1972).

AN50 Anonymous, "Reverse osmosis renovation of primary sewage", Aerojet-General Corporation, Water Pollut. Control Res. Series 17040 EFQ 02/71, EPA·WQO, U.S. (1971).

AN51 Anonymous, "Reverse osmosis systems in practice", Water and Waste Treatment, 13(1), 15-16 (1970).

AN52 Anonymous, "Reverse osmosis units dewater solutions", Chemical Engineering, p. 114, February 26 (1968).

AN53 Anonymous, "Rivers as resources", New Scientist, London, 46(696); 51, April (1970).

AN54 Anonymous, "ROGA* spiral wound reverse osmosis", Gulf Environmental Systems Product Bulletin, SP3214-13B, 1972; SP3214-20B, 1972; 3216, 0257207.

AN55 Anonymous, "Salt-rejecting membranes" Chemical and Engineering News, 10 March 1969, p. 25.

AN56 Anonymous, "Separation/Concentration of
- Carbohydrates: Bul 400, 2/1/72;
- Organic Acids & their Salts: Bul. 401, 1/2/72;
- Boric Acid & its salts: Bul. 402, 5/8/72;
- Ammonium and Nitrate ions: Bul 403, 5/8/72;
- Alcohols: Bul. 404, 20/9/72;
- Phenols: Bul. 405, 13/11/72",
duPont Permasep permeators, Technical Data Bulletin.

AN57 Anonymous, "The advantages of high quality water for industry from duPont permasep* permeators", Trade Literature, No. A-76388, undated.

AN58 Anonymous, "The B-9 permasep*", duPont Trade Literature, undated.

AN59 Anonymous, "The 1*Arno System: Reverse osmosis treatment systems", L*A Water Treatment Division, CHROMALLOY, Ind. Water Eng., 10(6), (1973).

AN60 Anonymous, "Treatment of acid mine drainage by reverse osmosis", Rex Chainbelt, Inc., Report dated March (1970). FWPCA-14010-DYK-03/70, W71-00477.

AN61 Anonymous, "Treatment of waste water--waste oil mixtures", Armco Steel Corp., Water Poll. Cont. Res. Series no. 12010 EZV 02/70 EPA·WQO, U.S. (1970).

AN62 Anonymous, "Trends in desalination", Nuclear Engineering, 13(149) 854-8 (1968).

AN63 Anonymous, "Ultrafiltration systems for dewatering and purification of electrocoating paints", Amicon Corporation publication no. 1010A, May (1971).

AN64 Anonymous, "Waste-water purification by reverse osmosis through hollow fibers", Chemical Engineering, New York, 77(26), 23, p. 51-52 Nov. 30 (1970).

AN65 Anonymous, "Wastewater treatment facilities for a polyvinyl chloride production plant", Goodrich, B.F., Chemical Company, Cleveland, Ohio, U.S. Environmental Protection Agency Report No. 12020DJI 06/71.

AN66 Anonymous, "Water from raw sewage", Chemical and Engineering News, 49(21), 11, May 24 (1971).

An67 Anonymous, "WS-430B water conservation/reclamation and silver recovery test", Tactical Air Reconnaissance Center, Shaw AFB, South Carolina, Report TRAC-8082-DT3105, April (1970).

AN68 Anonymous, "Why hollow-fiber reverse osmosis won the top CE prize for duPont", Chemical Engineering, November (1971).

B1 Baker, R.W., "Methods of fractionating polymers by ultrafiltration", J. Appl. Polym. Sci., 13, 369-376 (1969).

B2 Baker, R.W., "Ultrafiltration of macromolecular solutions with high-flux membranes", J. Appl. Polym. Sci., 14, 1197-1214 (1970).

B3 Baker, R.W., F.R. Eirich and H. Strathmann, "Low pressure ultrafiltration of sucrose and raffinose solutions with anisotropic membranes", J. Phy. Chem. 76(2), 238 (1972).

B4 Ballou, E.V., et al, "Solute rejection by porous glass membranes. I. Hyperfiltration of sodium chloride and urea feed solutions", Environ. Sci. & Technol., 5, 1032 (1971).

B5 Banks, W. and A. Sharples, "Studies on desalination by reverse osmosis; I. Structure and asymmetric flow properties of cellulose acetate desalination membranes", J. of Applied Chemistry, 16, 28-32 (1966).

B6 Banks, W. and A. Sharples, "Studies on desalination by reverse osmosis; III. Mechanism of solute rejection", J. of Applied Chemistry, 16, 153-158 (1966)

B7 Bansal, I.K., G.A. Dubey and A.J. Wiley, "Development of design factors for reverse osmosis concentration of pulping process effluents", Membrane Processes in Industry and Biomedicine Symposium, Plenum Press, New York, N.Y., 123-144 (1971).

B8 Bashaw, J.D., J.K. Lawson and T.A. Orofino, "Hollow fibre technology for advanced waste treatment", U.S. Nat. Tech. Inform. Serv., PB. Rep., 214605/8 (1973).

B9 Baum, B., S.A. Margosiak, W.H. Holley, Jr., C.M. Wong, W.S. Gillam, H.E. Podall and L.M. Kindley, "Study of methods to retard compaction of cellulose acetate membranes in reverse osmosis desalination", U.S. Office Saline Waters, Res. Develop. Progr. Rep. 467, (1969).

B10 Baum, B., et al, "Reverse osmosis membranes with improved compaction resistance", Ind. Eng. Chem., Prod. Res. Develop., 11(2), 195-9 (1972).

B11 Baum, B., et al, "Study of methods to retard compaction of cellulose acetate membranes in reverse osmosis desalination", Office Saline Water Report, OSW-PR-467, Oct. (1969). Contract DI-14-01-0001-1177.

B12 Bean, C.P., C.M. Wong, W.S. Gillian, H.E. Podall and L.M.Kindley, "Characterization of cellulose acetate membranes and ultrathin films for reverse osmosis", U.S. Office Saline Waters, Res. Develop. Progr. Rep. 465, (1969).

B13 Beckman, J.E., E. Vevege, J.E. Cruver, S.S. Kremen and I. Nusbaum, "Control of fouling of reverse osmosis membranes when operating on polluted surface waters", OSW-RDPR-73-882, U.S. Technical Information Service, PB-223 181, (1973).

B14 Beder, H. and W.J. Gillespie, "Removal of solutes from mill effluents by reverse osmosis", TAPPI, 53(5), 883-7 (1970)

B15 Beder, H. and W.J. Gillespie, "Solute removal via reverse osmosis", Ind. Water Eng., 6, 11 (1969).

B16 Belfort, G., F.E. Littman and H.K. Bishop, "Membrane regeneration for wastewater reclamation using reverse osmosis", Water Research, 7, 1567 (1973).

B17 Bemberis, I., "Systems for recreation developments - Septic tanks and package systems", Symposium on Engineering in Outdoor Recreation Development, University of Massachusetts, 9 November (1970).

B18 Bemberis, I., P.J. Hubbard and F.B. Leonard, "Membrane sewage systems - Potential for complete wastewater treatment", 1971 Winter Meeting, American Society of Agricultural Engineers, Chicago, Paper No. 71-878, Technical Reprint 9500, 10 December (1971).

B19 Bennett, P.J., S. Narayari and E. Hindin, "Removal of organic refractories by reverse osmosis", Eng. Bull. Purdue Univ., Eng. Ext. Ser., 132, 1000-1017 (1968).

B20 Bert, J.L., "Membrane compaction. A theoretical and experimental explanation", J. Polymer Science - Polymer Letters PT B, 7(9), 685-91 (1969).

B21 Besik, F.K., "Equipment for reverse osmosis and ultra-filtration separations", Water and Poll. Control, Canada, 108(8), 30 (1970).

B22 Besik, F.K., "Reverse osmosis-current systems and the future", Water and Poll. Control, Canada, 108(9), 46 (1970).

B23 Besik, F. et al, "Reverse osmosis; engineering considerations", Food Eng., 43, 72-5, July (1971).

B24 Besik, F., "Reverse osmosis in processing whey", Dairy Processing, Canadian Food Industries, 42(7), 32-35 (1971).

B25 Besik, F., "Waste water reclamation in a closed system", Water and Sewage Works, 118(7), 213-219 (1971).

B26 Besik, F., "Some aspects of reverse osmosis in treatment of domestic sewage", Water and Sewage Works, 119(10), 76-85 (1972).

B27 Besik, F., "Renovation of domestic wastewater", Water and Sewage Works, 120(4), 78-83 (1973).

B28 Besik, F.K., "Reverse osmosis treatment for corn processing effluent", Water and Pollution Control, 107(10), 24-26 (1969) and 107(11), 47-49 (1969).

B29 Bevege, E.E., et al, "Interaction of feedwater colloids with the surface of reverse osmosis membranes", Int-OSW-RDPR-73-883, U.S. National Tech. Inf. Service, PB-223 193/4, (1973).

B30 Bier, M., (ed.), "Membrane Processes in Industry and Biomedicine", Plenum Press, New York (1971).

B31 Bishop, H.K., "Use of improved membranes in tertiary treatment by reverse osmosis", Water Poll. Cont. Res. Series No. 17020 DHR 12/70, EPA.WQO, U.S. (1970).

B32 Bishop, H.K., G. Belfort, G.A. Guter, C.M. Wong, W.S. Gillam, H.E. Podall and L.M. Kindley, "In-situ formation of regenerative cellulose acetate membranes on porous tubular supports", U.S. Office Saline Water, Res. Develop. Progr. Rep. 464 (1969).

B33 Bittar, E. Edward, "Membranes and ion transport", 2, London, New York, Wiley-Interscience (1970).

B34 Bixler, H.J., R.W. Hausslein and L.M. Nelson, "Separation and purification of biological materials by ultrafiltration", National Meeting, American Institute of Chemical Engineering, Cleveland, May (1969).

B35 Bixler, H.J., R.A. Cross, C.M. Wong, W.S. Gillam and S. Johnson, "Final report on control of concentration polarization in reverse osmosis desalination of water", U.S. Office Saline Water, Res. Develop. Progr. Rep. 469 (1969).

B36 Blatt, W.F. et al, "An ultrafiltration membrane for the resolution and purification of bovine alphalactalbumin", Anal. Biochem. 18(1), 81 (1967).

B37 Blatt, W.F. et al, "A modified ultrafiltration cell for separating the products of proteolysis", Anal Biochem., 22(1), 161 (1968).

B38 Blatt, W.F., S.M. Robinson and H.J. Bixler, "Membrane ultrafiltration: the diafiltration technique and its application to microsolute exchange and binding phenomena", Analytical Biochemistry, 26(1), October (1968).

B39 Blatt, W.F., "Ultrafiltration, a preparative procedure for protein chemistry", Am. Laboratory, 21-30, March (1969).

B40 Blatt, W.F. et al, "Solute polarization and cake formation in membrane ultrafiltration: causes, consequences, and control techniques", Membrane Science and Technology, Plenum Press (1970).

B41 Blatt, W.F., "Membrane partition chromatography: a tool for fractionation of protein mixtures", Agriculture and food chemistry, 19(4), 589, July/Aug. (1971).

B42 Blatt, W.F. et al, "Rapid salt exchange by coupled ultrafiltration and dialysis in anisotropic hollow fibers", Separation Science, 7(3), 271-284 (1972).

B43 Blatt, W.F., "The application of selective ultrafiltration to protein chemistry", U.S. Army Research Institute of Environmental Medicine, Natick, Mass., Technical Report No. 68-40, January (1968).

B44 Blatt, W.F., and L. Nelsen, "Solute polarization and cake formation in membrane ultrafiltration: cause, consequences, and control techniques", Membrane Science and Technology: Ind., Biological and Waste Treatment Proc., J.E. Flinn (Ed.), Plenum Press, N.Y. (1970).

B45 Bopardikar, M.V. and S.B. Alagarsamy, "Brackish and/or waste water reclamation by electrodialysis process", Indian Chem. Mfg., 6(5-6), 33 (1968).

B46 Bossert, W.H., J.A. Hunter, W.F. Savage and K.C. Channabasappa, "Operation of a reverse osmosis desalination unit at Webster, South Dakota", U.S. Office Saline Water, Res. Develop. Progr. Rep. 427 (1969).

B47 Bowen, D.H.M., "Reverse osmosis for water demineralization", Ind. & Eng. Chem., 59(8), 40, Aug. (1967).

B48 Bowers, W.F. and R.H. Haschemeyer, "A versatile small-volume ultrafiltration cell", Anal. Biochem., 25, 549 (1968).

B49 Brandon, C.A. and J.S. Johnson et al, "Complete re-use of textile dyeing wastes processed with dynamic membrane hyperfiltration", American Society of Mechanical Engineers, Process Industries Division Joint ASME/EPA Reuse and Treatment of Waste Water, General Industry and Food Processing Symposium, New Orleans, La., March 28-30 (1972).

B50 Brandon, C.A., "Dynamic-membrane hyperfiltration. Key to re-use of textile dye waste", ASME, Paper 71, 5 (1971).

B51 Bray, D.T., "Reverse osmosis water purifying system with a gradient barrier water storage container", U.S. Patent 3726793 (1973).

B52 Bray, D.T., "Engineering of reverse osmosis plants", Chapter 6 in "Desalination by reverse osmosis", U. Merten (Ed.), M.I.T. Press, Cambridge, Mass. (1969).

B53 Bregman, J.I., "Membrane processes gain favor for water re-use", Environmental Science and Technology, 4(4), 296-302 (1970).

B54 Brinegar, W.C., "Reverse osmosis desalination of water employing polybenzimidazole membranes", U.S. Patent 3720607 (1973).

B55 Brock, J.L., P.M. Fahey, C.S. Miller, D.D. Spatz, J.A. Hunter, W.F. Savage and K.C. Channabasappa, "Development of low pressure reverse osmosis membranes and design of a small unit for brackish water", U.S. Office Saline Water, Res. Develop. Progr. Rep. 441 (1969).

B56 Brooks, T.W., C.L. Daffin, J.A. Hunter, W.S. Gillam and H.E. Podall, "Synthesis and evaluation of new membrane candidates for application in reverse osmosis", U.S. Office Saline Water, Res. Develop. Progr. Rep. 385 (1969).

B57 Brooks, T.W., C.L. Daffin, C.M. Wong, W.S. Gillam, H.E. Podall, and L.M. Kindley, "Synthesis and evaluation of new membrane candidates for application in reverse osmosis", U.S. Office Saline Water, Res. Develop. Progr. Rep. 460 (1969).

B58 Brown, J.H. and D.G. Conning, "Electrodialysis with moving membranes", U.S. Patent 3349021 (1967).

B59 Brown, R.L., "Removal of nitrogen from tile drainage", Calif. State Dept. of Water Resources, Summary report no. DWR-174-9; EPA-R2-71-6, EPA-13030-ELY-5/71-6 (PB 218 489/3). (From Govt. Rep. Ann., 73(11), 102, June 10 (1973)).

B60 Brunner, C.A., "Pilot-plant experiences in demineralization of secondary effluent using electrodialysis", Jour. WPCF, 39(10), R 1 (1967).

B61 Burley, M.J., D.G. Miller and J.T. West, "Quality aspects of water supply with particular reference to conventional and desalination treatment techniques", Chemical Engineering No. 224, CE408-CE415, Dec. (1968).

B62 Bundgaar, A.G., C.J. Cisen and R.P. Madsen, "Ultrafiltration and hyperfiltration of skim milk for production of various dairy products", Dairy Industries 37(10), 539 (1972).

B63 Burns, C.M., "Review of membrane processing of pulp mill effluents", CPAR Project 124-1 (1973).

B64 Burns, V.T., Jr., "Reverse Osmosis cuts solids", Water & Waste Eng., 11(5), C-6 (1974).

B65 Butterworth, T.A., D.I.C. Wang, A.J. Sinskey, "Application of ultrafiltration for enzyme retention during continuous enzymatic reaction", Biotech and Bioeng, XII, 615-631 (1970).

C1 Cadorette, J.W. and W.L. Adamson, "Reverse osmosis desalination system for deep-ocean vehicles", Naval Ship Research and Development Center, Annapolis, Maryland, Report, May, (1968), Project SF-013-01-01.

C2 Cadotte, J.E., et al, "In situ-formed condensation polymers for reverse osmosis membrane: The second phase of the fabrication and testing of tubular reverse osmosis modules containing ultrathin membranes for wet-dry cycling applications", Int-OSW-RDPR-73-874, U.S. Nat. Tech. Inf. Ser., PB-223 137/1 (1973).

C3 Cantor, P.A. and B.J. Mechalas, "Biological degradation of cellulose acetate reverse osmosis membranes", J. Polym. Sci., Part C., Polymer Symposia N. 28, 225-241 (1969); Also in OSW, Res. & Devel. Prog. Rep. No. 340, (1968).

C4 Cantor, P.A. and W.S. Higley, "Regeneration of cellulose acetate membranes", U.S. Office Saline Water, Res. Develop. Progr. Rep. 601 (1970).

C5 Carriere, F., "Purification of water by synthetic membranes", Chim. Mod. 15(92), 100-104, 106-107, 110 (1970).

C6 Castagna, C.J., "Obtaining high-purity water with reverse osmosis", Plant Eng., (Barrington, Ill), 27(10), 142-145 (1973).

C7 Catier, E., "Hyperfiltration: more suitable waters", Trait. Surface 12(105), 37, 39, 41-42 (1971).

C8 Cecil, L.K., "Water reuse and disposal", Chemical Engineering, 76(10), 92-104 (1969).

C9 Channabasappa, K.C., "Reverse osmosis process for water reuse application", Chem. Eng. Progr. Symp. Ser., 65(97), 140-147 (1969).

C10 Channabasappa, K.C., "Reverse osmosis process as a water supply system", Proc. Semin. Nucl. Power, 35-55 (1970).

C11 Channabasappa, K.C., "Use of reverse osmosis for valuable byproducts recovery", AIChE Symposium Series, 67(107), 250-259 (1971).

C12 Channabasappa, K.C. and F.L. Harris, "Economics of large-scale reverse osmosis plants", Ind. Water Eng., 7(10), 20-24 (1970).

C13 Chamberlin, R.M. and R.R. Stana, "Liquid treatment system for high-pH water", U.S. Patent 3737044, (1970).

C14 Chapman, C., "Electrodialysis for a developing country", Chem. and Process Eng., 48, 62 (1967).

C15 Charles, J.J., "Treatment of reverse osmosis raffinates by activated sludge", Journal, Water Pol. Cont. Fed., Washington, D.C., 43(3), 381-91.

C16 Charm, S.E. and C.J. Lai, "Comparison of ultrafiltration systems for concentration of biologicals", Biotechnol and Bioeng, XIII, 185 (1971).

C17 Chen, C. and C.A. Petty, "Flow characteristics of semipermeable hollow fibres undergoing reverse osmosis", Desalination, 12(3), 281-93 (1973).

C18 Cheng, C., S. Cheng and L. Fan, "Flow work exchanger", AIChE, 13, 438 May (1967).

C19 Chiang, E.S.K. and H.H.P. Fang, "Evaluation of new reverse osmosis membranes for the separation of toxic compounds from water", AIChE Symp. Ser., 70, 497-507 (1974).

C20 Chirrick, J.M., G.E. Foreman, A.B. Liedinger and W.W. Wright, "Development of large spiral membrane reverse osmosis elements for low-cost water purification and reclamation", Int-OSW-RDPR-73-901, U.S. National Tech. Inf. Service, PB-226 023/OGA, (1973).

C21 Chludzinski, P.J., "Tubular reverse osmosis membrane development using sulfonated polyphenylene oxide", Int-OSW-RDPR-73-881, U.S. Nat. Tech. Inf. Serv., PB-223 196/7, (1973).

C22 Chludzinski, P.J., A.P. Fickett and A.B. Laconti, "Characterisitics of hydrated sulfonated PPO (Polyphenylene oxide) reverse osmosis membranes", Polym. Prepr., Amer. Chem. Soc., Div. Polym. Chem., 12(2), 276-283 (1971).

C23 Chopey, N.P., "Reverse osmosis: Hollow fibers get tryouts", Chem. Eng. (N.Y.), 78(3), 28 (1971).

C24 Clifton, M.J. and R.T. Fowler, "Water purification by reverse osmosis. The state of the art", J. Inst. Eng., 44(9), 18-22 (1972).

C25 Cocconi, L., "Hyperfiltration treatment of industrial and municipal waste waters", Nuova Chim., 48(2), 71-73 (1972).

C26 Cohen, J.M., "Demineralization of waste-waters", Symposium on Nutrient Removal and Advanced Waste Treatment, FWPCA, U.S. Dept. of the Int., Cincinnati, Ohio (1969).

C27 Cohen, M.E., B.M. Riggieman, J.A. Hunter, W.S. Gillam, S. Johnson and R.H. Horowitz, "Development of improved cellulose acetate membranes for reverse osmosis", U.S. Office Saline Water, Res. Develop. Progr. Rep. 400 (1969).

C28 Cohen, M.E., B.M. Riggleman and P.D. Drechsel, "Composite cellulosic membranes for reverse osmosis", Appli. Polym. Symp. No. 13, 47-59 (1970).

C29 Cohen, M.E., M.A. Grable, B.M. Riggleman, C.M. Wong, W.S. Gillam, S. Johnson and R.H. Horowitz, "Second report on development of improved cellulose acetate membranes for reverse osmosis", U.S. Office Saline Water, Res. Develop. Progr. Rep. 518, (1970).

C30 Cohen, H. and S. Loeb, "Industrial waste water treatment in Israel using membrane processes", National Council for Research and Development, Report No. 132, Beer-Sheva, Israel, (1973).

C31 Cole, C.A., and E.J. Genetelli, "Decarbonation and Deaeration of Water by Use of Selective Hollow Fibers", Environ. Sci. and Technol., 4, 514 (1970).

C32 Cole, C.A. and E.J. Genetelli, "Pervaporation of volatile pollutants from water using selective hollow fibers", Jour. WPCF, 42(8), R290 (1970).

C33 Collins, J.W., L.A. Boggs, A.A. Webb and A.A. Wiley, "Spent sulfite liquor reducing sugar purification by ultrafiltration with dynamic membranes", TAPPI, 56 (6), 121-124 (1973).

C34 Conn, W.M., "Raw sewage reverse osmosis: Direct reclamation and phosphate removal", AIChE Symposium Series, 68(124), 294-299 (1972).

C35 Connelley, E.J., "Operating experiences with reverse osmosis plants in industry", Proc. Amer. Power Conf., 34th, 716-724 (1972).

C36 Cooke, W.P., "Hollow fiber permeators in industrial waste stream separations", Desalination, 7, 31 (1969).

C37 Crits, G.J., "Economic factors in water treatment", Ind. Water Engineering, 8(8), 22-29 (1971).

C38 Cross, R.A., "Asymmetric hollow fibers for ultrafiltration and dialysis", AIChE Symposium Series, 68(120), 15 (1972).

C39 Cruver, J.E., "Reverse osmosis treatment of water and wastewater", Marine Technol., 9(2), 216-222 (1972).

C40 Cruver, J.E. and I. Nusbaum, "Application of reverse osmosis to wastewater treatment", J.W.P.C.F., 46(2), 301 (1974).

C41 Cruver, J.E. et al., "Water Renovation of Municipal Effluents by reverse osmosis", E.P.A. Contract 14-2-831 (1972).

D1 Dagan, G. and A. Gollan, "Effect of porous backing substrates on membrane flux in reverse osmosis systems", Office Saline Water Report, OSW-PR-614, Contract DI-14-30-2528, Dec. (1970).

D2 Dance, E.L. et al, "Development of cellulose triacetate hollow fibre reverse osmosis modules for brackish water desalination", Office of Saline Water R&D Progress Report No. 763, Contract No. 14-01-0001-2248, December (1971).

D3 Davies, D.S., J.G. Canamare, J.A. Hunter, W.F. Savage and K.C. Channabassappa, "Development of a thin-liquid-film membrane unit for desalination by reverse osmosis", U.S. Office Saline Water, Res. Develop. Progr. Rep. 420, (1969).

D4 Dean, R.B., "Wastes from membrane processes", Environ. Sci. & Technology, 4(6), 453 (1970).

D5 DeBussy, R.P. and H.B. Whitmore, "Reverse osmosis: Some aspects of industrial water", National Engineer, 76(2), 10-14 (1972).

D6 DeHaven, C.G., E.R. Watson, J.A. Hunter, W.F. Savage and K.C. Channabasappa, "Operation of reverse osmosis pilot plants", U.S. Office Saline Water, Res. Develop. Progr. Rep. 422 (1969).

D7 DeFilippi, R.P. and R.L. Goldsmith, "Application and theory of membrane processes for biological and other macromolecular solutions", Membrane Science and Technology: Industrial, Biological and Waste Treatment Processes, Flinn, J.E. (ed.), Plenum Press, New York, 33-46 (1970).

D8 DeHaven, C.G., M.A. Jarvis and C.R. Wunderlich, "Operation of reverse osmosis pilot plants", Office Saline Water, Report PR-356, Contract DI-14-01-0001-1268, August (1968).

D9 Dejmek, P., "Prediction of reverse-osmosis-apparatus performance", Chem. Eng. Sci., 27(8), 1577-81 (1972).

D10 Demek, M.M., D.H. Rosenblatt and D.C. Lindsten, "Removal of toxic chemicals from water by reverse osmosis", Edgewood Arsenal, Report EA-TR-4356, March (1970).

D11 Denton, W.H., et al., "Reverse osmosis, electrodialysis, and freezing processes", Water Treat. Seventies, Proc. Symp., Chesterfield, Eng., 145-59 (1970).

D12 Desai, S.V., J.K. Smith, E. Klein and R.E.C. Weaver, "An economically attractive application of reverse osmosis to refinement of a petrochemical effluent stream", AIChE Symp. Series, 68(124), 379-87 (1972).

D13 Dewan, A.K., "Effect of variable viscosity and diffusivity on Laminar reverse osmosis systems between parallel plates", Masters Thesis, Clarkson College of Technology (1970).

D14 Dilli, S., J.L. Garnett, E.C. Martin and D.H. Phuoc, "Role of additives in the radiation-induced copolymerization of monomers to cellulose", J. Polym. Sci., Part C., 37, 57-118 (1972).

D15 Dismore, P.F., "Preservation of polyamide membranes for use in the reverse osmosis separation", U.S. Patent 3710945 (1973).

D16 Dodson, R.E., "Pure Water from Sewage", American City Magazine, 86(2), 43 (1971).

D17 Doshi, M.R., A.K. Dewan and W.N. Gill, "The effect of concentration dependent viscosity and diffusivity on concentration polarization in reverse osmosis flow systems", AIChE Symp. Series, 68(124) (1972).

D18 Doss, K.S.G., "Reverse osmosis process for desalination", Chem. Age India, 22(7), 453-59 (1971).

D19 Douglas, A.S., M. Tagami and C.E. Milstead, "Membrane materials for waste water reclamation by reverse osmosis", Water Pollut. Contr. Res. Ser. ORD-1704 EFOO 6/70, U.S. Dept. of the Interior, FWQA (1970).

D20 Douglas, A.S., M. Togami and H.K. Lonsdale, "Transport of organic solutes across semipermeable membranes", ACS, Division of Polymeric Chemistry, 10(2), September (1969).

D21 Dresner, L., "Boundary layer flow problems in desalination by reverse osmosis", Final Report to Office of Saline Waters (1970).

D22 Dryden, F.D., "Mineral removal by ion exchange, reverse osmosis and electrodialysis", Advanced Waste Treatment and Water Reuse Symposium, Dallas, Texas, Jan 12-14 (1971).

D23 Dryden, F.D., and G. Stern, "Demineralization of reclaimed water", Industrial Water Engrg., 8(7), 24 (1971).

D24 Dunkley, W.L., "Concentrating and fractionating whey", Report of Conference on Reverse Osmosis in Food Processing, U.S. Department of Agriculture, Albany, Calif., Report ARS74-51 (1969).

D25 Dupee, N.E., "Economics of feedwater treatment by reverse osmosis", Industrial Water Engineering, 10(5), 36-9 (1973).

D26 Duvel, W.A., Jr., "Molecular parameters affecting the removal of organic solutes from aqueous solution by reverse osmosis", Ph.D. Thesis, Dept. of Environmental Sciences, Rutgers University (1971).

D27 Dytnerskii, Y.I., A.A. Svittsov, Y.K. Romanenko, Y.N. Zhilin, V.P. Semenov and O.V. Trupchaninova, "Use of reverse osmosis and ultrafiltration during the purification of wastes", Bum. Prom., 7, 22-24 (1972).

D28 Dytnerskii, Y.I., R.G. Kocharov, G.V. Makarov and V.A. Minaev, "Purification of wastewaters by the reverse osmosis method", Khim. Prom. (Moscow), 47(12), 895-99 (1971).

E1 Eales, R., "Electrolyzed Sea water plays big role in sewage disposal method", Chem. Eng., 75, 172 (1968).

E2 Eden, G. E., K. Jones and T.D. Hodgson, "Recent developments in water reclamation", Chemical Engineer (London), 24-29 (1970).

E3 Eder, H.P., "Waste water treatment and recovery through reverse osmosis", AIChE Sym. Series, 69, 167-8 (1973).

E4 Eisenhauer, H.R., "Purification of sewage effluent by reverse osmosis", Dept. of National Health and Welfare, Ottawa, Canada, Rept. No. OR-70-11 (1970).

E5 Elata, C., "Development of concentrator of orange juice by reverse osmosis", Progress Report 352-1, Hydranautics-Israel, Ltd., Jan. 16 (1969).

E6 Ellender, R.D., F. Morton, J. Whelan and B.H. Sweet, "Concentration of virus from water by electroosmosis and forced-flow electrophoresis. II. Improvement of methodology and application to tap water", Preparative Biochemistry, 2(3), 215-228 (1972).

E7 Ellington, R.C., J.A. Hunter, W.S. Gillam, S. Johnson and R.H. Horowitz, "Development of water purification systems based on reverse osmosis", U.S. Office Saline Waters Res. Develop. Progr. Rep. 410 (1969).

E8 Erbland, J.F., R.W. Hausslein and J.M. Cohen, "Wastewater fractionation using low pressure membrane ultrafiltration", Amer. Chem. Soc., Div. Water, Air Waste Chem., Gen. Pap., 10(2), 177-181 (1970).

E9 Erickson, L.E., J.T. Tseng, C.L. Hwang, C.Y. Cheng and L.T. Fan, "Analysis of a reverse osmosis water purification system and its optimization based on the plug flow model for the bulk flow in the membrane unit", Kansas State Univ-Institute for Systems Design and Optimization Report 13 (1969).

E10 Eubank, F.J., "Industrial desalting-water supply and waste disposal", Water and Wastes Eng., 6, Feb. 10 (1969).

E11 Evans, D.R., and J.C. Wilson, "Actual capital and operating costs for advanced waste treatment", Proc. 43rd annual WPCF Conf. (held in Boston, Mass., Oct. 4-9, 1970); Jour. WPCF, 44(1), 1 (1972).

E12 Ewoldson, E.I., et al, "Brackish water desalting testing and evaluation procedures with mobile test facility", Int-OSW-RDPR-73-885, U.S. Nat. Tech. Inf. Ser., PB-223 352/6 (1973).

F1 Fahey, P.M. and H.E. Grethlein, "Improved cellulose acetate membranes for reverse osmosis", Desalination, 9(4), 297-313 (1971).

F2 Fallick, G.J., "Industrial ultrafiltration", Process Biochemistry, 4(9) (1969).

F3 Fan, L.T., C.L. Hwang, L.E. Erickson, C.Y. Cheng and L.Y.S. Ho, "Analysis and optimization of a reverse osmosis water purification system. I" Kansas Unit, Institute for systems Design and Optimization Report 14 (1969).

F4 Fan, L.T., C.Y. Cheng, L.S. Ho, C.L. Hwang and L.E. Erickson, "Analysis and optimization of a reverse osmosis water purification system. II. Optimization", Desalination, 6(2), 131-152 (1969).

F5 Fan, L.T., J.T. Tseng, L.E. Erickson and C.L. Hwang, "Optimization of a multistage reverse osmosis desalination system based on the plug flow model for the bulk flow in the membrane unit", Kansas State Univ., Inst. for Systm. Design and Optimization Rep. 27 (1971).

F6 Feige, W.A., J.M. Smith, "Waste water applications with a tubular reverse osmosis unit", AIChE Symp. Ser., 70, 523-33 (1974).

F7 Feuerstein, D.L. and T.A. Bursztynsky, "Design considerations for treatment of solids - laden wastewaters by reverse osmosis", Chem. Eng. Progr. Symp. Ser., 67(107), 568-574 (1971).

F8 Feuerstein, D.L. and T.A. Bursztynsky, "Reverse osmosis renovation of municipal wastewater", Water Pollut. Contr. Res. Ser. ORD-17040EFQ12/69, U.S. Dept. of the Int., FWQA (1969).

F9 Fisher, B.J. and J.R. Lowell, Jr., "New technology for treatment of wastewater by reverse osmosis", Water Pollut. Contr. Res. Ser. 17020DUD09/70, EPA.WQO, U.S. (1970).

F10 Flinn, J.E. (Ed.), "Membrane Science and Technology: Industrial, Biological and Waste Treatment Processes", Plenum Press, N.Y. (1970).

F11 Flowers, L.C., P.K. Lee, E.S. Boeer, M.H. Gjersten, D. Eerg, J.A. Hunter, W.S. Gillam and J. Johnson, "Graphite oxide containing reverse osmosis membranes", U.S. Office Saline Water, Res. Develop. Prog. Rep. 418 (1969).

F12 Fluke, G.A. J.A. Hunter, W.F. Savage and K.C, Channabasappa, "Process and configuration development for tubular reverse osmosis units", U.S. Office Saline Water Res. Develop. Progr. Rep. 426 (1969).

F13 Fluke, G.A. and W.H. Bossert, "Operation of a reverse osmosis desalination unit at Webster, South Dakota", U.S. Office Saline Water, Research and Development Progress Report, OSW-PR-427, May (1969). Contract DI-14-1-1000-1181.

F14 Fluke, G.A., J.A. Hunter, W.F. Savage and K.C. Channabasappa, "New design concept for reverse osmosis membrane cells", U.S. Office Saline Water, Res. Develop. Progr. Rep. 428 (1969).

F15 Fluke, G.A., "Development of tubular reverse osmosis module assembly techniques", Office Saline Water Report, OSW-PR-582 (1970). Contract DI-14-01-0001-2163.

F16 Forbes, F., "Role of ultrafiltration in industrial effluent problems", Chemistry & Industry (London), 56-8 (1974).

F17 Ford, A., Jr., "Evaluation of high flux reverse osmosis membranes on Potomac River water", U.S. Army Mobility Equipment Research and Development Center Report, January 9 (1970).

F18 Foreman, G.E., S.S. Kremen, "Role of reverse osmosis in water resource management", AIChE Symp. Ser., 70, 491-6 (1974).

F19 Foreman, G.E., et al, "Development of second generation spiral membrane reverse osmosis elements", Int-OSW-RDPR-73-875, U.S. Nat. Tech. Inf. Ser., PB-223 191/8 (1973).

F20 Fossum, J.H., "Water reclamation by reverse osmosis", U.S. Clearinghouse Fed. Sci. Tech. Inform., 1969(6), 54 (1969); also Melpar, Incorporated, Falls Church, Virginia, Report No. 7256 (1969).

F21 Freman, G.E., S.S. Kremen and J.F. Loos, "Development and testing of large spiral-wound reverse osmosis modules", Office Saline Water Report, OSW-PR-677, Apr. (1971). Contract DI-14-01-0001-2107.

F22 Fremont, H.A., D.C. Tate and R.L. Goldsmith, "Color removal from kraft mill effluents by ultrafiltration", Environmental Protection Technology Series, EPA-660/2-73-019, U.S., (1973).

F23 Frommer, M.A., I. Feiner, O. Kedem and R. Bloch, "The mechanism for formation of 'skinned' membranes", Desalination, 7, 393-402 (1970).

F24 Frommer, M.A., R. Matz and U. Rosenthal, "Mechanism of Formation of reverse osmosis membranes", Ind. Eng. Chem. Prod. Res. Develop., 10(2), 193-196 (1971).

F25 Fuji, H., "Effect of flow rate in the axial direction on hyperfiltration", Kagaku Sochi, 15(4), 79-84 (1973).

F26 Furukawa, D.H., "RO: Packed with potential", Water and Wastes Eng., 8(11), F14 (1971).

F27 Furukawa, "Flushing techniques to restore flux in reverse osmosis plants", U.S. Bureau of Reclamation, December 16 (1968).

G1 Gembicki, S.A., et al, "Computer system for the description and evaluation of community water systems based on reverse osmosis desalination", Int-OSW-RDPR-73-876, U.S. Nat. Tech. Inf. Service, PB-223 184/3 (1973).

G2 Gentry, R.E., Jr., "Reverse osmosis", Environ. Sci. & Tech., 1(2), 124 (1967).

G3 Gilbert, G.B., et al, "Development of flow work exchangers for energy recovery in reverse osmosis plants", Office Saline Water Report, OSW-PR-672, April (1971). Contract DI-14-01-0001-2213.

G4 Gilbert, G., "Development of flow work exchangers for energy recovery in reverse osmosis plants", Office Saline Water Report, OSW-PR-680, April (1971). Contract DI-14-01-0001-2213.

G5 Giliam, W.S. and H.E. Podall, "Recent developments on the reverse osmosis process for desalination", Desalination, 9(3), 201-211 (1971).

G6 Gill, W.N. and B. Bansal, "Hollow fibre reverse osmosis systems analysis and design", AIChE Journal, 19(4), 823-831 (1973).

G7 Gill, W.N., L.J. Dersansky, and M.R. Doshi, "Mass transfer in laminar and turbulent hyperfiltration systems", Office of Saline Water Report No. 403 (1969).

G8 Gill, W.N., L.J. Derzansky, and M.R. Doshi, "Convective diffusion in laminar and turbulent hyperfiltration (reverse osmosis) systems", Colloid and Surface Science, 4, 261-360 (1971).

G9 Gilliland, E.R., S.M. Fleming and S.M. Nemser, "Structure-property relationship for membrane permeation", MIT Annual Report, 1969-70, April (1970).

G10 Ginnette, L.F., and R.L. Merson, "Maximum permeation rates in reverse osmosis concentration of viscous materials", AIChE Meeting, St. Louis, Paper No. 29d, Feb. 19 (1969).

G11 Ginnette, L.F. and R.L. Merson, "Maximum permeation rate in reverse osmosis concentration of viscous materials", Presented 63rd Nat. Mtg., AIChE St. Louis, Feb. 18-21 (1968).

G12 Gittens, G.J., P.A. Hitchcock, D.C. Sammon and G.E. Wakley, "Structure of cellulose acetate membranes for reverse osmosis, I. Membranes prepared from a dioxan based dope", Desalination, 8(3), 369-391 (1970).

G13 Gittens, G.J., P.A. Hitchcock and G.E. Wakley, "The structure of cellulose acetate membranes for reverse osmosis, II. Transmission and scanning electron microscopy of membranes cast from an acetone-formamide dope", Desalination, 12, 315-332 (1973).

G14 Gjessing, E.T., "Ultrafiltration of aquatic humus", Environ. Sci. and Tech., 4(5), 437 (1970).

G15 Glater, J., et al, "Calcium sulfate scale control in high temperature desalting processes", UCLA-ENG-7364, Int-OSW-RDPR-73-888, U.S. Nat. Tech. Inf. Service, PB-223 386/4 (1973).

G16 Glueckauf, E., "On the mechanism of osmotic desalting with porous membranes", First International Symposium on Water Desalination, Washington, D.C., 143-150, Oct. 3 (1965).

G17 Glueckauf, E. and D.C. Sammon, "Transport of ions and water through cellulose acetate membranes", 3rd International Symposium on Fresh Water from the Sea, 2, 397-422 (1970).

G18 Goff, D.L. and E.F. Gloyna, "Reverse osmosis developments", Univ. of Texas Press, Water Quality Improvement by Physical and Chemical Processes, 312-326 (1970).

G19 Goff, D.L. and Gloyna, E.F., "Concentration of cobalt solutions by reverse osmosis", U.S. Army Aberdeen Research and Development Center. Bullistic Research Laboratories, Aberdeen Proving Ground, Md., Report No. 1449 (1969).

G20 Goldsmith, H., H. Lolachi, C.M. Wong, W.S. Gilliam, S. Johnson and R.H. Horowitz, "Test cell for measuring the concentration polarization boundary layer in a reverse osmosis system", U.S. Office Saline Water, Res. Develop. Progr. Rep. 527 (1970).

G21 Goldsmith, R.L., D.J. Goldstein, B.S. Horton, S.Z. Hossain and R. Robert, "Ultrafiltration for control of pollution caused by cottage cheese whey", Ind. Aliment. (Italy), 10(77), 85-96 (1971).

G22 Goldsmith, R.L. and B.S. Horton, "Membrane processing of cottage cheese whey for pollution abatement", Water Pollution Control Series 12060 DXF 07/71, EPA.WQO, U.S. (1971).

G23 Goldsmith, R.L., S. Hossain and M. Tan, "Testing reverse osmosis modules for washwater recycling", Int-OSW-RDPR-73-877, U.S. Nat. Tech. Inf. Service, PB-223 195/9 (1973).

G24 Goldsmith, R.L., et al, "New membrane-process applications", AIChE Symp. Ser. 68(120), 7-14 (1972).

G25 Gollan, A. and G. Dagan, "Effect of porous backing substrates on membrane flux in reverse osmosis systems", Desalination 8(3), 261-275 (1970).

G26 Golomb, A. and F. Besik, "Reverse osmosis for wastewater treatment", Ind. Water Eng., 7(10), 16-19 (1970).

G27 Golomb, A. and F. Besik, "Reverse osmosis - A review of its applications to waste treatment", Ont. Ind. Waste Conf., Proc. 17, 67-97 (1970).

G28 Golomb, A., "Application of reverse osmosis to electroplating waste treatment. I. Recovery of nickle", Plating, 57(10), 1001-1005 (1970).

G29 Golomb, A., "Application of reverse osmosis to electroplating waste treatment. II. Potential role of reverse osmosis in the treatment of some plating wastes", Plating, 59(4), 316-319 (1972).

G30 Golomb, A., "Application of reverse osmosis to electroplating waste treatment. III. Pilot plant study and economic evaluation of nickel recovery", Plating, 60(5), 482-486 (1973).

G31 Goodall, J.B. and W.F. Lorch, "Reverse osmosis. A review of techniques and systems with particular reference to water purification", Elga Progr., 9(2), 5-12 (1970).

G32 Gouveio, A., and K.A. Hooton, "Potable water from hospital waste by reverse osmosis", Chem. Eng. Prog. Symposium Series, 64(90), 280 (1968).

G33 Govindan, T.S., and S. Sourirajan, "Reverse osmosis separation of some inorganic salts in aqueous solution using porous cellulose acetate membranes", Ind. and Eng. Chem., Process Design and Develop., 5, 422 (1966).

G34 Graber, F.M., H.K. Lonsdale, C.E. Milstead and B.P. Cross, "Boron rejection by cellulose acetate reverse osmosis membranes", Desalination, 7(1), 249-258 (1969).

G35 Greyson, J., and H.H.Rogers, "Dewatering sewage sludge by electro osmosis", Jenkins, S.H. (Ed.), Advances in Water Pollution Research, Vols. I and II, Pergamon Press: Oxford, England (1971).

G36 Grieves, R.B., D. Bhattacharyya, W.G. Schomp and J.L. Bewley, "Membrane ultrafiltration of a nonionic surfactant", AIChE J., 19(4), 766-774 (1973).

G37 Grieves, R.B., J.T. Schredt, and S. Kelman, "Electrodialysis of Monocarboxylic Acid Salts", AIChE J. 14, 963 (1968).

G38 Griffith, W.L., R.M. Keller, D.G. Thomas and W.J. Boegley, Jr., "Effect of brine disposal cost on hyperfiltration plant optimization", Desalination, 11(1), 91-112 (1972).

G39 Griffith, W.L. et al, "Hyperfiltration studies XIII. Parametric study of hyperfiltration in tubular systems with high permeability membranes", Desalination, 4, 283-308 (1968).

G40 Groepl, R. and W. Pusch, "Asymmetric behaviour of cellulose acetate membranes in hyperfiltration experiments as a result of concentration polarisation", Desalination, 8(3), 277-292 (1970).

G41 Gross, M.C., J. Markind and R.R. Stana, "Membrane experience in food processing", AIChE Symp. Ser., 69(129), 81-88 (1973).

G42 Gross, M.C. and R.R. Stana, "Use of reverse osmosis for removal of detergents from nuclear waste water", Proc. Amer. Power Conf., 34, 710-715 (1972).

G43 Grover, J.R. and M.H. Delve, "Operating experience with a 23MG/day reverse osmosis pilot plant", Chem. Eng. (London), 257(1), 24-29 (1972).

G44 Grover, J.R., "New developments in water treatment at the atomic energy research establishment. 2. Reverse osmosis", Chem. Ind. (London), 8, 369-370 (1973).

G45 Gubanov, A.M., "Purification of waste waters from electroplating shops by hyperfiltration", Vodosnabzh. Sanit. Tekh., 3, 10-11 (1973).

G46 Gugliermotte, F., "Flat-modulus device for reverse osmosis", German Patent 2213150, (1972).

G47 Gupta, M. and D.G. Mason, "Amenability of reverse osmosis concentrate to activated sludge treatment", Water Pollut. Cont. Res. Ser. 17040EUE 07/71, U.S. Dept. of the Int., FWQA, (1971).

H1 Habgood, H.W., "Alberta group devices helium recovery system", The Globe and Mail, Toronto, January 5 (1974).

H2 Hamer, E.A.G., "Tubular osmotic membrane", U.S. Patent 3715036 (1973).

H3 Hamer, E.A.G., R.L. Kalish, C. Wong, W.F. Savage and K.C. Channabasappa, "Reverse osmosis membrane regeneration", U.S. Office Saline Water, Res. Develop. Progr. Rep. 471 (1969).

H4 Hamer, E.A.G., J.A. Hunter, W.F. Savage and K.C. Channabasappa, "Design, fabrication and testing of a 1000 gallon per day tubular reverse osmosis pilot plant", U.S. Office Saline Water, Res. Develop. Progr. Rep. 424 (1969).

H5 Hamil, H.F., W.W. Harlowe Jr., C.M. Wong, W.S. Gillam, H.E. Podall and L.M. Kindley, "Development of modified polyolefin membranes for reverse osmosis", U.S. Office Saline Water, Res. Develop. Progr. Rep. 530 (1970).

H6 Hardt, F.W., L.S. Clesceri, N.L. Nemerow and D.R. Washington, "Solids separation by ultrafiltration for concentrated activated sludge", J. Water Pollut. Contr. Fed., 42(12), 2135-48 (1970).

H7 Hardt, F.W., J.C. Young, L.S. Clesceri and D.R. Washington, "Ultrafiltration for the control of recycled solids in a biological system", Eviron. Sci. Technol., 5(4), 345-9 (1971).

H8 Hardwick, W.H., "Water renovation by reverse osmosis", Chemistry & Industry (Brit.), 9, 297 (1970).

H9 Harriott, P., "Mechanism of partial rejection by ultrafiltration membranes", Separ. Sci., 8(3), 291-307 (1973).

H10 Harriott, P. and D.L. Michelsen, "The effect of compression on membrane permeability", Office Saline Water Report, OSW-PR-330, Contract DI-14-01-0001-750.

H11 Harris, F.L., G.E. Humphreys, H. Isakari, G. Reynolds, C.M. Wong, W.F. Savage and K.C. Channabasappa, "Engineering and economic evaluation study of reverse osmosis", U.S. Office Saline Water, Res. Develop. Prog. Rep. 509 (1969).

H12 Hatfield, G.E. and G.W. Graves, "Optimization of a reverse osmosis system using nonlinear programming", Desalination, 7(1), 147-77 (1969).

H13 Hauck, A.R. and S. Sourirajan, "Performance of porous cellulose acetate membranes for the reverse osmosis treatment of hard and waste waters", Environmental Science and Technology, 3(12), 1269-75 (1969).

H14 Hauck, A.R. and S. Sourirajan, "Reverse osmosis treatment of diluted nickel-plating solutions", J. Water Pollut. Control Fed., 44(7), 1372-83 (1972).

H15 Havens, G.G. and D.B. Guy, "The use of porous fiberglass tubes for reverse osmosis", AIChE Symp. Series 64(90), 299 (1968).

H16 Helfgott, T., J.V. Hunter, W.A. Duvel, Jr., "Analytic and process classification of wastewaters", Chem. Eng. Symp. Series, 67(107), 388-400 (1971).

H17 Helfgott, T., and J.V. Hunter, "Removal of phosphates from waste waters by electrodialysis", Chem. Eng. Progr. Symp. Series, 65(97), 218-31 (1969).

H18 Henderson, L.W. et al., "Uremic blood cleansing by diafiltration using a hollow fibre ultrafilter", Trans. Amer. Soc. Artif. Int. Organs, XVI, 107 (1970).

H19 Hendricks, T.J. and F.A. Williams, "Diffusion-layer structure in reverse osmosis channel flow", Desalination, 9(2), 155-180 (1971).

H20 Hendricks, T.J. and F. Williams, "Boundary layer flow problems in desalination by reverse osmosis", Final Report to Office of Saline Water, June (1970).

H21 Hester, J.C. and C.A. Brandon, "Hyperfiltration technique applied to wash water reclamation at elevated temperatures", ASME Paper No. 73-ENAS-27 (1973).

H22 Hickman, K.E., J.P. Tramoni, J.T. Ganley, E.J. Fahimian, K.C. Channabasappa and W.F. Savage, "Pumping and energy recovery systems for reverse osmosis desalination plants", U.S. Office Saline Waters, Res. Develop. Progr. Rep. 457 (1969).

H23 Higdon, R.E., "Understanding reverse osmosis", A.M. City, 87(12), 55-6 (1972).

H24 Higley, W.S., "Collagen membranes for reverse osmosis desalination", U.S. Patent 3, 644, 202, U.S. National Tech. Inf. Service, PB-225, 419, (1970).

H25 Hill, R.D., R.C. Wilmoth, R.B. Scott, "Neutrolosis treatment of acid mine drainage", U.S. Nat. Tech. Inform. Serv., PB Rep. 213690/4 (1971).

H26 Hindin, E., G.H. Dunstan and P.J. Bennett, "Water reclamation by reverse osmosis", Bulletin 310, College of Eng. Research Division, Sanitary Eng. Section, Washington State Univ., (1968).

H27 Hindin, E., P.J. Bennet and S.S. Narayanan, "Organic compounds removed by reverse osmosis", Water & Sewage Works, 116(12), 466-470 (1969).

H28 Hindin, E., P.J. Bennett, "Water reclamation by reverse osmosis", Water & Sewage Works, 116(2), 66-73 (1969).

H29 Hochscherf, E.K., and G. Mandee, "Manufacture of semipermeable membranes and their application in reverse osmosis and ultrafiltration", Chem-Ing-Tech., 46(20), 1152-60 (1972).

H30 Hodgson, T.D., "Selective properties of cellulose acetate membranes towards ions in aqueous solutions", Desalination, 8(1), 99-138 (1970).

H31 Hopfenberg, H.B., et al. "Preparation and properties of grafted membranes for desalination - I", J. Polym. Sci., Part C, Polymer Symposia, n 28, 243-60 (1969).

H32 Hopfenberg, H.B., et al., "Novel membranes prepared by radiation grafting of styrene to cellulose acetate", ACS Symposium, Membranes from Cellulose and Cellulose Derivatives, Minneapolis, April 1969, Applied Polymer Symposia No. 13 (A.F. Turbak, ED.), Interscience Publishers, (1970).

H33 Horton, B.S., et al., "Membrane processing of cheese whey reaching commercial scale", Food Techn. 26, 30-2, February (1972).

H34 Hossain, S., R.L. Goldsmith, M. Tan, T. Wydeven and M.I. Leban, "Evaluation of 165 deg. F. reverse osmosis modules for washwater purification", ASME Paper No. 73-ENAS-2 (1973).

H35 Hubbard, P.J. and I. Bemberis, "Shipboard waste treatment system, Phase I", General Dynamics, Electric Boat Division, Groton, Conn., Final Report, Nov. (1971).

H36 Huffman, E., Lacey, R., "Engineering and economic considerations in electromembrane processing", Chapter 3 in "Industrial Processing with Membranes", R. Lacey and S. Loeb, Editors, Wiley, New York (1972).

H37 Hurwich, B.J., "Preparation of water by reverse osmosis for hemodialysis and coil storage and reuse", Israel Journal of Medical Sciences, 8(5), 602 (1972).

H38 Huymann, E., and H.J. Mueller, "Reverse osmosis-new process in water purification", Brauwelt, 111(21), 387-88 (1971).

H39 Horowitz, H., "Synthesis of modified loeb membranes by grafting", U.S. Dept. of the Interior, Research and Development Progress Report No. 545, Contract No. 14-01-0001-1322, June 1972.

I1 Illner-Paine, O., "Reverse osmosis- cheaper food, purer water", Science Journal, 6(12), 53-55 (1970).

I2 Ironside, R. and S. Sourirajan, "The reverse osmosis membrane separation technique for water pollution control", Water Research 1(2), 179-180 (1967).

I3 Ishizaki, S., S. Suzuki, K. Kosaka and T. Nakamura, "Fundamental study on the treatment of secondary sewage effluent by reverse osmosis", Kogyo Yosui, (164), 16-22 (1972).

I4 Itoi, S., "Waste water treatment by ion exchange membrane", Nenryo Oyobi Nensho, 39(7), 625-39 (1972).

I5 Iwai, S., "Decoloring of waste water", Senryo To Yakuhin, 17(5), 159-165 (1971).

I6 Iwai, S., T. Kitao and M. Sugawara, "Treatment of heavy metals by reverse osmosis", Kyoto Daigaku Kogaku Kenkyusho Iho, 40, 57 (1971).

J1 Jackson, J.M. and D. Landolt, "About the mechanism of formation of iron hydroxide fouling layers on reverse osmosis membranes", Desalination, 12(3), 361-378 (1973).

J2 Jacqueme, M., "Industrial ultrafiltration - its applications to recovery and purification of macromolecules", Chimie & Industrie-Genie Chimique, 105(15), C 34 (1972).

J3 Jagur-Grodzinski, J., S. Marian and D. Vofsi, "The mechanism of a selective permeation of ions through 'solvent polymeric membranes'", Weizmann Inst. of Sci., Plastics Res. Dept. Sep. Sci., 8(1), 33-44, February (1973).

J4 Jameson, T.A. and T.H. Meltzer, "A review of cellulosic membrane applications to air, water and biological fluids filtration", ACS Symp., Membranes from cellulose and cellulose derivatives, Minneapolis, April (1969); Applied Polymer Symposia No. 13 (A.F. Turbak, Ed.), Interscience Publishers, (1970).

J5 Jennett, J.C., and C.C. Patterson, "Treatability of reverse osmosis raffinates by activated sludge", Jour. WPCF, 43(3), 381 (1971).

J6 Jennett, J.C., "Aerobic treatment characteristics of the raffinates from a reverse osmosis waste water reclamation plant",Thesis, Engineering, University of New Mexico, Albuquerque, New Mexico, (1969).

J7 John, J., "California based system for the automated detection of heavy metals in inland waters", Nuclear Methods in environmental research, Topical Meeting, Abstracts. (Held in Columbia, Mo., 23-24 Aug. 1971.) Sponsored by American Nuclear Society, and University of Missouri, Columbia.

J8 Johnson, A.R. and A.C. Acrivos, "Concentration polarization in reverse osmosis under natural convection", Ind. and Eng. Chem. - Fundamentals, 8(2), 359-361 (1969).

J9 Johnson, J.S. and J.W. McCutchan, "Concentration polarization in the reverse osmosis desalination of sea water", Desalination, 10(2), 147-156 (1972).

J10 Johnson, J.S. and J.W. McCutchan, "Desalination of sea water by reverse osmosis", AIChE Symp. Series, 69(129), 493-507 (1973).

J11 Johnson, J.S. Jr., et al, "Hyperfiltration. XXI. Dynamically formed hydrous zirconium (IV) oxide-polyacrylate membranes", J. Electroanat. Chem. Interfacial Electrochem. 37, 267-81 (1972).

J12 Johnson, J.S. et al, "Separations Processes", Office Saline Water Report, OSW-PR-508, Fe. (1970). Contract KI-14-01-001-937.

J13 Johnson, J.S. and D.N. Bennion, "Mass transport in reverse osmosis membranes", Chem. Eng. Progress Sym. Series, 64(90), 270-279 (1968).

J14 Johnston, H.K. and S. Sourirajan, "Effect of secondary additives in casting solution on the performance of porous cellulose acetate reverse osmosis membranes", J. Applied Polymer Sci., 17, 2485 (1973).

K1 Kafes, N.C. and C.W. Clump, "Turbulent and laminar mass transfer in a tubular membrane", AIChE J., 19, 1247-9 (1973).

K2 Kaup, E.G., "Design factors in reverse osmosis", Chem. Eng., 80(8), 46-55 (1973).

K3 Kaup, E.G., "Reclamation of acidic mine drainage waters by ion exchange and reverse osmosis", AIChE Symp. Ser., 70, 577-62 (1974).

K4 Kay, M., F.J. Quinn, M.W. Marshall and H. Meikle, "Recovery and pollution control by reverse osmosis: a pilot installation", Br. Kinematogr. Sound Telev., 54(12), 328-31 (1972), Also in J. of the Soc. of Motion Picture Television Eng., 81(6), 461-64 (1972).

K5 Kedem, O., "Water and salt transport in hyperfiltration", Reverse Osmosis Membrane Res., 17-42 (1972).

K6 Kelin, E., et al., "Polymeric materials for treatment and recovery of petrochemical wastes", Water Pollut. Cont. Res. Ser. 12020 DQC 03/71, EPA·WQO, U.S. (1971).

K7 Kepinski, J., and N. Chlubek, "Application of filtration through semipermeable membranes for treatment of wastes", Przem. Chem. (Pol.), 50(12), 788 (1971).

K8 Kepinski, J. and N. Chlubek, "Removal of detergents from industrial wastes by hyperfiltration", Przem. Chem., 51(2), 107-109 (1972).

K9 Kepinski, J. and N. Chlubek, "Investigations of purification of industrial wastes from detergents by hyperfiltration", International Chemical Engineering, 12(3), 499 (1972).

K10 Kesting, R.E., "Synthetic Polymeric Membrane", McGraw Hill, N.Y., 1971.

K11 Kesting, R.E., "Preparation of reverse osmosis membranes by complete evaporation of the solvent system", Patent Application U.S. National Tech. Inf. Service, PAT-APPL-401 003 (1973).

K12 Kesting, R.E., M.K. Bursh and A.L. Vincent, "Semipermeable membranes of cellulose acetate for desalination in the process of reverse osmosis (II) parameters affecting membrane gel structures", J. Appl. Poly. Sci., 9, 1873 (1965).

K13 Kesting, R.E., W.J. Subcasky and J.D. Paton, "Liquid membranes at the cellulose acetate membrane/ saline solution interface in reverse osmosis", J. Colloid and Interface Sci., 28(1), 156 (1968).

K14 Kimura, N., "Desalination of sea water by reverse osmosis and its application for food industries", Shokuhin Kogyo, 15(18), 63-72 (1972).

K15 Kimura, S.G., "Reverse osmosis performance of sulfonated poly (2,6- dimethylphenylene ether) ion exchange membranes", Ind. Eng. Chem., Prod. Res. Develop., 10(3), 335-339 (1971).

K16 Kimura, S. and S. Sourirajan, "Concentration polarization effects in reverse osmosis using porous cellulose acetate membranes", I/EC Process Design and Development, 7, 41-48, Jan. (1968).

K17 Kimura. S. and S. Sourirajan, "Performance of porous cellulose acetate membranes during aqueous solutions", I/EC Process Design and Development, 7, 197-206, (NRC-9959, 1968), April (1968).

K18 Kimura, S. and S. Sourirajan, "Mass transfer coefficients for use in reverse osmosis process design", I/EC Process Design and Development 7(4), Oct. (1968).

K19 Kimura, S. and S. Sourirajan, "Transport characteristics of porous cellulose of sucrose in aqueous solutions", I/EC Process Design and Development, 7(4), Oct (1968).

K20 Kimura, S., S. Sourirajan and H. Ohya, "Stagewise reverse osmosis process design", I/EC Process Design and Development, 8(1), Jan. (1969).

K21 Kindiey, L.M., H.E. Podall and J.N. Pecoraro, "Application of reverse osmosis to wash water recovery for manned space flights", ASME paper 71-AV-1 (1971).

K22 King, W.M., P.A. Cantor, L.W. Schoellenbach and C.R. Cannon, "High retention, reverse osmosis desalination membranes from cellulose acetate", Appl. Poly. Symp., (13), 17-25 (1970).

K23 Kirkpatrick, F.W., Jr., and E.F. Smythe, "History and possible future of multiple reuse of sewage effluent at the Odessa, Texas Industrial Complex", Chem. Eng. Progr., 63, 78 (1967).

K24 Klein, E., J.K. Smith, F. Morton and B.H. Sweet, "Concentration of virus from water by osmotic ultrafiltration -2, Mass transport aspects", Water Res., 5(11), 1067-77 (1971).

K25 Klein, E., et al., "Ultrafiltration as a method for concentrating Rift Valley fever virus grown in tissue culture", Appl. Microbiol., 21(4), 758 (1971).

K26 Kline, G.M., "Cellulose acetate membranes for waste water purification", Modern Plastics, 45(5), (1968).

K27 Kliu, M., "Iternative analysis of a continuous system for desalination by reverse osmosis", Desalination, 9(2), 181-91 (1971).

K28 Klunker, F. and P. Harriott, "The permeability of membranes filled with silica gel", AIChE Symp. Series, 68(124), 340-48 (1972).

K29 Knapp, C.E., "Membrane processing upgrades food wastes", Environmental Science and Technology, 5(5), 396-97, May (1971).

K30 Kneale, J.S., et al., "Cost effectiveness study on pretreatment methods for membrane Desalting plants", Office Saline Water Report, OSW-PR-425, Contract DI-14-01-0001-1259, May (1969).

K31 Kollsman, P., "Reverse osmosis", U.S. Patent No. 3, 462, 362, Aug. 19 (1969).

K32 Kopecek, J. and S. Sourirajan, "Performance of porous cellulose acetate membranes in some reverse osmosis experiments", Ind. & Eng. Chem-Product Research & Development, 8(3), 274-79 (1969).

K33 Kopecek, J. and S. Sourirajan, "Structure of porous cellulose acetate membranes and a method for improving their performance", J. Appl. Polym. Sci., 3, 637 (1969).

K34 Kopecek, J. and S. Sourirajan, "Performance of porous cellulose acetate membranes for the reverse osmosis separation of mixtures of organic liquids", Indus. and Eng. Chem., Process Design and Development, 9(1), Jan. (1970).

K35 Kraus, K.A., A.J. Shor and J.S. Johnson, Jr., "Hyperfiltration studies X. Hyperfiltration with dynamically-formed membranes", Desalination, 2, 243 (1967).

K36 Kraus, K.A., "Application of hyperfiltration to treatment of municipal sewage effluents", Water Pollut. Cont. Res. Series ORD-17030 EOM 01/70, FWQA, U.S. (1970).

K37 Kremen, S.S., "Capabilities of reverse osmosis for volume production of high-purity water and reclamation of industrial waste streams", Proc. Amer. Power Conf., 32, 799-816 (1970).

K38 Kremen, S.S. and J.H. Myers, "Reverse osmosis application in the chemical industry", ACS Symposium, Membranes from Cellulose and Cellulose Derivatives, Minneapolis, April 1969, Applied Polymer Symposia No. 13 (A.F. Turbak, Ed.), Interscience Publishers (1970).

K39 Kremen, S.S., "Reverse osmosis for water and waste treatment", 31st International Water Conference, Engineers Society of Western Pennsylvania, Pittsburgh, 27-29 Oct. (1970) (Print No. Gulf-EN-10327A).

K40 Kremen, S.S., et al., "Reverse osmosis field testing on acid mine waste at Norton, West Virginia", U.S. Office of Saline Water, Research and Development Progress Report No. 586, (1970).

K41 Kugelman, I.J., W.A. Schwarta and J.M. Cohen, "Advanced waste treatment plants for treatment of small waste flows", Advanced Waste Treatment and Water Reuse Symposium, Dallas, Texas, January (1971).

K42 Kuiper, D., C.A. Bom, J.L. VanHezel and J. Verdown, "The use of reverse osmosis for the treatment of Rhine River water. Part I", Desalination 14(2), 163-72, (1974).

K43 Kulshrestha, V.K. and W.J. Koff, "Novel regenerated cellulose membranes for the artificial kidney", ACS Symposium, Membranes from Cellulose and Cellulose Derivatives, Minneapolis, April 1969, Applied Polymer Symposia No. 13 (A.F. Turbak, Ed.,) Interscience Publishers, (1970).

K44 Kunst, B. and S. Sourirajan, "Development and performance of some porous cellulose acetate membranes for reverse osmosis desalination", J. Appl. Polym. Sci., 14(10), 2559-68 (1970).

K45 Kuo, W.L., "Separation of caprolactam in aqueous solution by reverse osmosis", Chem. Eng. Progr. Symp. Ser., 64(90), 291-8 (1968).

K46 Kurbiel, J., "Water renovation processes and perspectives for their application", Pr. Nauk, Inst. Inz. Sanit. Wodnej. Politech. Wroclaw., 10, 45-62 (1971).

L1 Lacey, R.E., "Membrane separation processes", Chemical Engineering, 79(19), 56-74 (1972).

L2 Lacey, R.E., "The costs of reverse osmosis", Chapter IX in "Industrial processing with membranes", R. Lacey and S. Loeb, editors, Wiley, New York (1972).

L3 Lacey, R., "An electromembrane process for regenerating acid from spent pickle liquor", Final report on Contract 12010EQF, Environmental Protection Agency, Mar. (1971).

L4 Lacey, R.E., (Ed.), "Membrane processes for industry", Southern Research Institute, Birmingham, Ala., (1966).

L5 Lacey, R.E., and S. Loeb, "Industrial processing with membranes", Wiley-Interscience, (1972).
Chapter IX - "The cost of reverse osmosis", by R.E. Lacey
Chapter XII - "The treatment of industrial wastes by pressure-driven membrane processes", by R.B. Okey
Chapter VIII - "Theory and practice of reverse osmosis and ultrafiltration", by H.K. Lonsdale.

L6 Lacey, R.E. and E.L. Huffman, "Demineralization of wastewater by the transport - depletion process", Water Pollut. Cont. Res. Series, 17040.EUN 02/71, EPA.WQO, U.S. (1971).

L7 Laconti, A.B., J.M. Amore and J.F. Enos, "Development of sulfonated polyphenylene oxide membranes for the reverse osmosis purification of wash water at sterilization temperatures", ASME Paper 73-ENAS-16 (1973).

L8 Larson, T.J., B.C. Gibbons, J.A. Hunter, W.F. Savage and K.C. Channabasappa, "Reverse osmosis membrane module (Spiral-wound concept)", U.S. Office Saline Water, Res. Develop. Progr. Rep. 442, (1969).

L9 Larson, T.J., "Reverse osmosis pilot plant operation. A spiral module concept", Desalination 7(1), 187-199 (1969).

L10 Larson, T.J., "Purification of subsurface waters by reverse osmosis", Gulf General Atomic, Inc., Report No. GA-7819 (1967).

L11 Lawhon, J.T., S.H.C Lin, C.M. Cater and K.F. Mattil, "Recycling of effluent from membrane processing of cottonseed wheys", Food Technol., (Chicago), 27(2), 26-7, 30, 32, 34 (1973).

L12 Lawrence, R.W., et al, "Development of storage techniques for reverse osmosis membranes", Office Saline Water Report, OSW-PR-673, April (1971). Contract DI-14-01-0001-1666.

L13 Lawrence, R.W., and C.W. Saltonstall, Jr., "Reverse osmosis for wash water recovery in space vehicles", ASME Paper 73-ENAS-12, (1973).

L14 LeBras, L.R. and R.M. Christenson, "Ultrafiltration - A process aid in electrocoating", J. of Paint Technol., 44(566), 63 (1972).

L15 LeGros, P.G., et al, "Systems analysis of brine disposal from reverse-osmosis plants", U.S. Office Saline Water, Report No. OSW-PR-587, (1970).

L16 LeGros, P.G., C.E. Gustafson, B.P. Shepherd and W.F. McIlhenny, "Systems analysis of brine disposal from reverse osmosis plants", U.S. Office Saline Water, Res. Develop. Progr. Rep. 587, (1970).

L17 Lsightell, B., "Reverse osmosis (RO). How it works, what it costs", Filtr. Separ. 8(6), 715-18, 720 (1971).

L18 Leitner, G.F., "Reverse osmosis for waste water treatment", Metal Progr., 98(6), 62-63 (1970).

L19 Leitner, G.F., "Pollution control operations - reverse osmosis for water recovery and reuse", Chemical Engineering Progress, 69(6), 83-85 (1973).

L20 Leitner, G.F., "Reverse osmosis for waste water treatment. What. When", TAPPI, 55(2), 258-261 (1972).

L21 Leitner, G.F. and R.M. Ahlgren, "Water reclamation, waste utilization", Heating, Piping & Air Cond., 42, 127 (1970).

L22 Leonard, F.B., and J.S. DeMurley, "Profitable recovery of pollutants", Ind. Process Des. Water Pollut. Contr., Proc. Workshop, 69-75 (1971).

L23 Leonard, R.L., D.F. Carey and T.A. Orofino, "Apparatus for water purification by reverse osmosis", Ger. Offen. Patent 2239931, (1973).

L24 Leonard, R.L., "Development of high-flux hollow reverse osmosis fibers for brackish water softening", Int-OSW-RDPR-73-872, U.S. National Tech. Inf. Service, PB-225 102/5 (1973).

L25 Leonard, R.L. and T.A. Orofino, "Hollow fine fibers for brackish waters softening", Int-OSW-RDPR-73-887, U.S. Nat. Tech. Inf. Ser., PB-223 384/9, (1973).

L26 Lepper, F.R., Jr., "Reverse osmosis: Larger plants and wider use", Power Eng., 77(5), 56-59 (1973).

L27 Le Rat, B., "Reverse osmosis process, desalination of water by means of the cellulose acetate membrane", Bull Inform. Sci. Tech. (Paris), 3-14 (1969).

L28 Leszczynski, C., and J. Zielinski, "Application of reverse osmosis for waste water treatment in the pulp and paper industry", Przegl. Papier., 26(11,12), 385-389 (1970).

L29 Levy, D., "Reclamation of municipal waste water for reuse", Negev Inst. for Arid Zone Research, Eng. Sci. Div., rep. NEG-ES-73-1/1, Mar. (1973).

L30 Lewis, U.S., E.V. Cheever and B.K. Seavay, "Aggregate-free human growth hormone isolation by ultrafiltration", Endocrinol., 84(2), 325 (1969).

L31 Lindner, G., "Refuse treatment from a chemist's point of view", Dechema Monogr., 64(1144-1167), 295-314 (1970).

L32 Littman, F.E., G.A. Guter, C.M. Wong, W.S. Gillam and H.E. Pidall, "Research on porous glass membranes for reverse osmosis", U.S. Office Saline Water, Res. Develop. Progr. Rep. 505 (1970).

L33 Litz, L.M., "Useful products from reverse osmosis", Proc. of the 32nd Annual Conf. on Chemurgy for Better Environment and Profit, held in Washington, D.C., Oct. 22-23, 1970, sponsored by Chemurgic Council, New York City, 119-133 (1970).

L34 Liu, M.K., "Water desalination by reverse osmosis", Diss Abstr. Int. Sec. B., Univ. Microfilms, 32(4), 2184-B (1971).

L35 Liu, M.K., "Perturbation analysis of a continuous system for desalination by reverse osmosis", Appl. Sci. Res., 26(5), 349-360 (1972).

L36 Loeb, S and M.R. Bloch, "Countercurrent flow osmotic processes for the production of solutions having a high osmotic pressure", Desalination, 13, 207-215 (1973).

L37 Loeffler, I. and M. Bradbury, "Reverse osmosis separator", Fr. Patent 2116612, (1972).

L38 Lolachi, H., "Direct measurement of concentration polarization boundary layer in reverse osmosis desalination systems", Diss. Abstr. Int. Sec. B., Univ. Microfilms, 32(9), 1604-B (1971).

L39 Lonsdale, H.K., U. Merten and M. Tagami, "Phenol transport in cellulose acetate membranes", J. Appl. Polym. Sci., 11(9), 1807-1820 (1967).

L40 Lonsdale, H.K., C.E. Milstead, B.P. Cross, F.M. Graber, J.A. Hunter, W.S. Gillam, H.E. Podall and L.M. Kindley, "Study of rejection of various solutes by reverse osmosis membranes", U.S. Office Saline Water, Res. Develop. Progr. Rep. 447 (1969).

L41 Lonsdale, H.K., R.L. Riley, L.D. Lagrange, C.R. Lyons, A.S. Douglas, U. Merten, C.M. Wong and W.S. Gillam, "Research on improved reverse osmosis membranes", U.S. Office Saline Water, Res. Develop. Progr. Rep. 484, (1969).

L42 Lonsdale, H.K. et al, "Permeability of cellulose acetate membranes to selected solutes", ACS, Division of Polymer Chemistry, 10(2), September (1969).

L43 Lonsdale, H.K., U. Merten and R.L. Riley, "Transport properties of cellulose acetate osmotic membranes", J. Appl. Poly. Sci., 9, 1341 (1965).

L44 Lonsdale, H.K., "Theory and practice of reverse osmosis and ultrafiltration", Chapter VIII in "Industrial Processing with membranes", R. Lacey and S. Loeb, editors, Wiley, New York, (1972).

L45 Lowe, E., E.L. Durkee, R.L. Merson and A.I. Morgan, Jr., "Wurstack - A reverse osmosis unit for food use", 27th Annual Meeting of the Institute of Food Technologists, Minneapolis, Minnesota, Paper No. 13, (1967).

L46 Lowe, E., E.L. Durkee, and A.I. Morgan Jr., "Concentration and fractionation of whey by reverse osmosis", Food Technology, (22), 969 (1968).

L47 Lowe, E., E.L. Durkee, and A.I. Morgan, Jr., "A reverse osmosis unit for food use", Food Technology, 22, 103-105, July (1968).

L48 Lowe, E., et al, "Egg white/concentrated by reverse osmosis", Food Technology, (23), 45 (1969).

L49 Lukavyi, L.S. and Y. Dytnerskii, "Separation of homogeneous liquid mixtures by reverse osmosis", Int. Chem. Eng., 9(3), 458-464 (1969).

L50 Lyali, C.E., B.O. Bennett, and L.R. Hogan, "Water purification system", Fr. Patent 2126970, (1972).

M1 Mabrouk, A.F. "Preparation of aqueous beef flavor precursor concentrate by selective ultrafiltration", J. Agr. Food Chem., 21, 943-7 (1973).

M2 Maconochie, G., G. Thomas, C.M. Wong, W.S. Gillam, H.E. Podall and L.M. Kindley, "New synthetic membranes for reverse osmosis desalination", U.S. Office Saline Water, Res. Develop. Progr. Rep. 533, (1970).

M3 Madsen, R., O. Olsen, I.K. Nielsen and W.K. Nielsen, "Experience with concentration and separation of industrial solutions with reverse osmosis and ultrafiltration", Filtr. Sep., 9(5), 567-575 (1972).

M4 Mahon, H.I. et al, "Hollow fiber membranes for selective permeation", Chem. Eng. Progress Symposium Ser. 65(91), 48-51 (1969).

M5 Mahon, H.I. and B.J. Lipps, "Hollow-fiber membranes", Encyl. Polym. Sci. Technol. 15, 258-72 (Eng) (1971). Edited by Norbert M. Bikales; Interscience: New York, N.Y.

M6 Mahoney, J.G., M.E. Rowley and L.E. West, "Industrial waste treatment opportunities for reverse osmosis", Membrane Sci. Technol.: Ind. Biol. Waste Treat. Process, Flinn, J.E. (Ed.), Plenum Press, N.Y., 196-219 (1970).

M7 Malz, F., "Chemistry and technology of advanced waste-water purification. State of the art and future problems", Vom Wasser, 38, 319-325 (1971).

M8 Manjikian, S., J.A. Hunter, W.F. Savage and K.C. Channabasappa, "Reverse osmosis pilot plant for desalination of sea water", U.S. Office Saline Water, Res. Develop. Progr. Rep. 448 (1969).

M9 Manjikian, S., S. Liu, M. Foley, E. Faerick, C.M. Wong, W.S. Gillam, and H.E. Podall, "Development of reverse osmosis membranes", U.S. Office Saline Water, Res. Develop. Progr. Rep. 534, (1970).

M10 Manjikian, S. and W.K. Windle, "Reverse osmosis module", U.S. patent 3, 774, 771 (1973).

M11 Marquardt, K., "Fresh water and waste water treatment by reverse osmosis and ultrafiltration compared with, or as a complement to ion exchange techniques", Metalloberflaeche, 27(5), 169-182 (1973).

M12 Martin, F.E., "Drying cellulose acetate membrane with polyvinyl methyl ether", U.S. patent 3, 373, 056, (1968).

M13 Mason, C., "Membrane regeneration and cleaning", Second Biennial Symposium on Reverse Osmosis, Office of Saline Water, Miami, Florida, April 27 (1969).

M14 Mason, D.G., "Treatment of acid mine drainage by reverse osmosis", Proceedings, Third Coal Mine Drainage Research Symposium, Ohio River Valley Water Sanitation Commission, Coal Industry Advisory Committee, Cincinnati, Ohio.

M15 Mason, D.G.,"Engineering evaluation of reverse osmosis and ion exchange demineralization for use in a self-contained, air-transportable wastewater renovation unit", Rex Chainbelt, Inc., Milwaukee, Wisc., Interim technical report, July (1968); Contract: DAAKO2-67-C-0398.

M16 Mason, D.G. and M.K. Gupta, "Reverse osmosis demineralization of acid mine drainage", Water Pollut. Cont. Res. Ser. 14010 FQR 03/72, EPA.WQO, U.S., (1972).

M17 Masse, A.N. and R.T. Miele, "Reverse osmosis for wastewater renovation", Paper No. 35C pres. 61st Annual Meeting of the Amer. Inst. Chem. Engr., Los Angeles, Calif. (1968).

M18 Matsuura, T., "Use of the reverse osmotic pressure method in waste water treatment", Kagaku Kogaku, 35(4), 419-429 (1971).

M19 Matsuura, T., and S. Sourirajan, "Studies on reverse osmosis for water pollution control", Water Research, 6(9), 1073-1086 (1972).

M20 Matsuura, T. and S. Sourirajan, "Physicochemical criteria for reverse osmosis separation of alcohols, phenols, and monocarboxylic acids in aqueous solutions using porous cellulose acetate membranes", J. Appl. Polym. Sci. 15(12), 2005-27 (1971).

M21 Matsuura, T. and S. Sourirajan, "Reverse osmosis separation of phenols in aqueous solutions using porous cellulose acetate membranes", Journal of Applied Polymer Science, 16, 2531-2554 (1972).

M22 Matsuura, T. and S. Sourirajan, "Physicochemical criteria for reverse osmosis separations of aldehydes, ketones, ethers, esters, and amines in aqueous solutions using porous cellulose acetate membranes", J. Appl. Polym. Sci., 16(7) (1972).

M23 Matsuura, T. and S. Sourirajan, "Physicochemical criteria for reverse osmosis separation of monohydric and polyhydric alcohols in aqueous solutions using porous cellulose acetate membranes", J. of Appl. Polym. Sci., 17(4), 1043-1071 (1973).

M24 Matsuura, T., M.E. Bednas, and S. Sourirajan, "Reverse osmosis separation of single and mixed alcohols in aqueous solutions using porous cellulose acetate membranes", J. Appl. Polym. Sci., 18, 567 (1974).

M25 Mattson, P.J. and V.J. Tomsic, "Improved water quality", Chem. Eng. Progress, 65(1), 62-8, Jan. (1969).

M26 Matz, R., "Structure of cellulose acetate membranes - 1. the development of porous structures in anisotropic membranes", Desalination, 10(1), 1-15 (1972).

M27 Matz, R., "Surface phenomenon occurring during the preparation of cellulose acetate reverse osmosis membranes", Desalination, 12(2), 273-275 (1973).

M28 McCandles, F.P., "Separation of aromatics and naphthalenes by permeation through modified vinylidene fluoride films", Ind. Eng. Chem. Process Design Developments, 12, 354 (1973).

M29 McCrobbie, H.W., L.M. Litz, J.A. Hunter, W.F. Savage and K.C. Channabasappa, "Reverse osmosis permeators. A design study", U.S. Office Saline Water, Res. Develop. Progr. Rep. 423, (1969).

M30 McCutchan, J.W. and J.S. Johnson, "Reverse osmosis at Coalinga, California", J. Amer. Water Works Assn. 62(6), 346-353 (1970).

M31 McDonough, F.E. and R.E. Hargrove, "Sanitation of reverse osmosis and ultrafiltration equipment", J. Milk Food Technol. 35(2), 102-106 (1972).

M32 McDonough, F.E., "Concentration and fractionation of whey by reverse osmosis", Proceedings, Whey Utilization Conference, University of Maryland, 2-3 June (1970).

M33 McGarvey, F.X., "Stateside", Effluent and Water Treatment Journal, 10(9), 545, Sept. (1970).

M34 McKinney, R., Jr., "Reverse osmosis separations with aromatic polyamide films and hollow fibers", Separ. Purif. Methods, 1(1), 31-115 (1972).

M35 McKenney, R., Jr. and J.H. Rhodes, "Aromatic polyamide membranes for reverse osmosis separations", Macromolecules 4(5), 633-7 (1971).

M36 McKinney, R., et al, "Development of polyamide membranes for sea water desalination", Int-OSW-RDPR-73-886, U.S. Nat. Tech. Inf. Ser., PB-223 385/6, (1973).

M37 Meares, P., "On the mechanism of desalination by reverse osmotic flow through cellulose acetate membranes", European Polymer Journal, 2, 241-254 (1966).

M38 Mehta, D.V., "Influence of processing variables on the desalination characteristics of low flux cellulose acetate membranes", Diss. Abstr. Int. Sec. B, Univ. Microfilms, 32(3), 1534-B (1971).

M39 Meinecke, E.A. and D.V. Mehta, "Influence of some processing variables on the properties of cellulose acetate membranes - 1, 2, 3", Desalination, 10(4), 341-382 (1972).

M40 Meinecke, E.A. and D.V. Mehta, "Preparation of high flux cellulose acetate membranes and hollow fibers from prefabricated low flux specimens", Patent Application, U.S. Nat. Tech. Inf. Ser. PAT-APPL-383.233, (1973).

M41 Menzel, H.F., "Parametric study of a one MGD brackish water reverse osmosis plant (spiral module concept)", Office Saline Water Report, OSW-PR-236. Contract DI-14-01-0001-426.

M42 Merana, P., "Concentration of Chromium-51 Liquid water by reverse osmosis and by metallic sorption", Unpublished special problem report, Dept. of Civil Eng., Sanitary Eng., Washington State U., Pullman, Washington, (1967).

M43 Merson, R.L., L.F. Ginnette and A.J. Morgan, "Reverse osmosis for food processing", Dechema (Deut. Ges. Apparatewesen) Monogr., 63(1125), 179-201 (1969).

M44 Merson, R.L. and A.I. Morgan, Jr., "Reverse osmosis for food concentration", OSW Research Conference on reverse osmosis, San Diego, Calif., 13-15 February (1967).

M45 Merson, R.L. and A.I. Morgan, Jr., "Juice concentration by reverse osmosis", USDA - Agriculture Research, Food Technology, 22, 99-100, May (1968).

M46 Merson, R.L. and L.F. Ginnette, "Improved processing of foods by reverse osmosis", ACS Symposium, Membranes from Cellulose and Cellulose Derivatives, Minneapolis, April (1969). Applied Polymer Symposia No. 13 (A.F. Turbak, Ed.), Interscience Publishers, (1970).

M47 Merten, U., (Ed.), "Desalination by reverse osmosis", M.I.T. Press, Cambridge, Mass. (1966).

M48 Merten, U., I. Nusbaum and R. Miele, "Organic removal by reverse osmosis", Amer. Chem. Soc., Div. Water, And Waste Chem., Gen. Pap., 8(2), 24-31 (1968).

M49 Merten, U., "Reverse osmosis in waste-water treatment", Air Water Pollut., Proc. Summer Workshop 1970, Brittin, W.E. (Ed.), Colo. Association Univ. Press, Colo. p. 155-175 (1972).

M50 Merten, U. and D.T. Bray, "Reverse osmosis for water reclamation", Munich Abstracts - Section III, J. WPCF, 38(3), 397-398 (1966). Also in Advan. Water Pollut. Res., Proc. Int. Conf., 3, 315-331 (1967).

M51 Michaels, A.S., "Fundamentals of membrane permeation", Membrane Process Ind., Proc. Symp., Birmingham, Ala., p. 157-195 (1966).

M52 Michaels, A.S., "Separation technique for the chemical process industry", Chem. Eng. Proc., 64(12), 31-43 (1968).

M53 Michaels, A.S., H.J. Bixler, R.A. Cross, D.S. Cleveland and B. Carroll, "Development of a disposable membrane cartridge for reverse osmosis desalination", Amicon Corp. OSW R&D Prog. Rep. No. 795 (PB 214 954/0), May 1972. (From Govt. Rep. Ann., 73(7), Apr. 10 (.973)).

M54 Michaels, A.S., "Ultrafiltration" in "Progress in Separation and Purification", 1, E.S. Perry, (Ed.), Interscience, London, (1968).

M55 Miller, C.S. and D. Spatz, "Research and development on low pressure reverse osmosis membranes and design of a small unit for brackish water", Office Saline Report, OSW-PR-339, March (1968). Contract DI-14-01-0001-939.

M56 Miller, E.F., "Lowering cost of reverse osmosis desalting", Chem. Eng., 75(24), 153-158 (1968).

M57 Milligan, W.O., et al, "Inorganic semipermeable membranes", Office Saline Water Report, OSW-RDPR-71-723, October (1971). Contract DI-14-01-0001-1296.

M58 Mills, A.R., "Reverse osmosis for purification of water -1", Solid State Technol., 13(7), 41-45 (1970).

M59 Mills, A.R., "Reverse osmosis for purification of water -2", Solid State Technol., 13(8), 71-75 (1970).

M60 Milstead, C.E., A.B. Riedinger and H.K. Lonsdale, "Rejection of carbon dioxide and pH effects in reverse osmosis desalination", Desalination, 9(3), 217-223 (1971).

M61 Minturn, R.E., "Calcium sulfate scaling in reverse osmosis (hyperfiltration) of brackish waters by hollow-fiber and spiral-wound modules", U.S. National Tech. Inf. Service ORNL-TM-4330, (1973).

M62 Mixon, F.O. "The removal of toxic metals from water by reverse osmosis", U.S. National Tech. Inf. Service No. PB-223 449/0, (1973).

M63 Model, F.S., et al, "The influence of hydroxyl ratio on the performance of reverse osmosis desalination membranes", Office Saline Water Report, OSW-PR-657, June (1971).

M64 Moore, R.E., "Water purification by reverse osmosis", Aust. Chem. Process. Eng. 25(2), 9-12 (1972).

M65 Morris, D.C., W.R. Nelson and G.O. Walraven, "Recycle of paper-mill waste waters and application of reverse osmosis", Water Pollut. Cont. Series, 12040 FUB 01/72, EPA.WQO, U.S., (1972).

M66 Morris, D.C., W.R. Nelson and G.O. Walraven, "Use of reverse osmosis in treatment of weak semichemical waste water", Water Sewage Works, 118(9), 124A (1971).

M67 Morrison, M.C., "Economic analysis of acid whey protein recovery", Brochure from Calgon-Havens Systems Div., Calgon Corp., Pittsburgh, Pa., (1970).

M68 Murkes, J., and H. Bohman, "Mathematical modeling of reverse osmosis and ultrafiltration processes", Desalination, 11(3), 269-301 (1972).

M69 Myers, J.H., "Reverse osmosis for industrial water and waste treatment", ASME paper 70-PEM-21, (1970).

M70 Myers, J.H., "Reverse osmosis can cut cost of water treatment", Industrial Water Engg., 7(3), 25 (1970).

N1 Nakane, T. and S. Ishizaka, "Reverse osmosis separation of heavy metal salts in aqueous solutions", Nippon Kaisui Gakkai-Shi, 26(139), 11-15 (1972).

N2 Nefedova, G.Z., N.E. Kozhevnikava, L.I. Gracheva, S.A. Tverskaya and E.A. Kotyakhov, "Possible use of hyper- and ultrafiltration for purifying waste and mine waters", Tsvet. Metal., 45(3), 48-51 (1972).

N3 Nelson, W.R., and G.O. Walraven, "A role for reverse osmosis in a neutral sulphite semichemical pulp and paperboard mill", Proc. 23rd Intl. Waste Conf. Part One. IN: Purdue University, Lafayette, Industrial Engg. Ext. Series No. 132, 540-549 (1968).

N4 Nelson, W.R. and G.O. Walraven, "Reverse osmosis proves highly effective", Pulp and Paper, 30, August 19 (1968).

N5 Nelson, W.R., G.O. Walraven and D.C. Morris, "N.S.S.C. mill experience with waste water reuse and reverse osmosis", TAPPI Environmental Conference, New Orleans, April 17-19 (1974).

N6 Nelson, W.R., G.O. Walraven and D.C. Morris, "Process water reuse and upset control modification at an integrated neutral sulfite semichemical mill", TAPPI, 56(7), 54 (1973).

N7 Nickelson, R.L., E.A. Birkhimer, D.E. Coverdell, J.Y. Lai, D.G.J. Wang, C.M. Wong, W.S. Gillam and R.H. Horowitz, "Membranes for reverse osmosis by direct casting on porous supports", U.S. Office Saline Water, Res. Develop. Progr. Rep. 520, (1970).

N8 Nielsen, I.K., "Concentration and separation of dairy products with DDS ultrafiltration-reverse osmosis system", brochure from De Danske Sukkerfabrikker, Langebrogade-5, DK-1001, Copenhagen, Denmark.

N9 Nielsen, I.K., A.G. Bundgaard, O.J. Olsen and R.F. Madsen, "Reverse osmosis for milk and whey", Process Biochem. 7(9), 17-20 (1972).

N10 Nierstrasz, H., "Cyclic processes in the plating industry", Water and Pollution Control, 109(7), 20-24, 27, July (1971).

N11 Nikolaevskaya, Z.S. and M.S. Aizen, "Detection of minimal concentrations of viruses in large volumes by ultrafiltration through soluble lanthanum-aluminum-alginate ultrafilters", Vop. Virusol., (6), 723-726 (1972).

N12 Nishiwaki, T., "Concentration of electrolytes with an electromembrane process", Chapter VI in "Industrial Processing with Membranes", R. Lacey and S. Loeb, editors, Wiley, New York, (1972).

N13 Nomura, D., "Reverse osmosis and its application to orange-processing industry waste water treatment", Mizu Shori Gijutsu, 13(2), 21-27 (1972).

N14 Nozaki, H., "Separation of water and salt from seawater by reverse osmosis across charged membranes", Asahi Garasu Kogyo Gijutsu Shoreikai Kenkyu Hokoku, 19, 313-329 (1971).

N15 Nusbaum, I., J.E. Cruver, and J.H. Sleigh, Jr., "Reverse osmosis - new solutions and new problems", AIChE Symp. Series, 68(124), 270-282 (1972).

N16 Nusbaum, I., J.H. Sleigh, Jr., and S.S. Kremen, "Study and experiments in waste water reclamation by reverse osmosis", Water Pollut. Cont. Res. Series No. 17040---05/70, U.S. Dept. of the Int., FWQA, (1970).

01 Ohya, H. and S. Sourirajan, "Reverse osmosis separation of urea in aqueous solutions using porous cellulose acetate membranes", Ind. Eng. Chem., Process Design and Development, 8, Jan. (1969).

02 Ohya, H. and S. Sourirajan, "Some general equations for reverse osmosis process design", Al. Chem. Eng. Jour. 15(6), 829-836, Nov. (1969).

03 Okey, R.W., "Phosphorus removal in membrane waste water treatment", U.S. Patent 3, 398, 088 (1968).

04 Okey, R.W., "The Application of membranes to sewage and waste treatment", IN: Water Quality Improvement by Physical and Chemical Processes, Univ. of Texas Press, 326-338 (1970).

05 Okey, R.W., and P.L. Stavenger, "Membrane Technology: A progress report", Ind. Water Eng., 4, 36 (1967).

06 Okey, R.B., "The treatment of industrial wastes by pressure-driven membrane processes", Chapter XII in "Industrial processing with membranes", R. Lacey and S. Loeb, editors, Wiley, N.Y. (1972).

07 Ossowski, J., "Effect of flocculation on the effectiveness of electroosmotic drainage of lime sludges", Pr. Nauk. Inst. Geotech. Politech. Wroclaw., 11, 63-38 (1972).

08 Osterhoudt, H.W., "Transport properties of Eastman cellulose acetate membranes. Influence of diffusant size and shape on permeability", J. Appli. Polym. Sci., 15(3), 597-606 (1971).

09 O'Sullivan, A.C., "Whey processing by reverse osmosis ultrafiltration and gel filtration", Daily Indus., 636, November (1971).

010 Otten, G. and G.D. Brown, "Reverse osmosis removal efficiencies of bacteria and pyrogens in water treatments", American Laboratory, 49, Dec. (1973).

N13 Nomura, D., "Reverse osmosis and its application to orange-processing industry waste water treatment", Mizu Shori Gijutsu, 13(2), 21-27 (1972).

N14 Nozaki, H., "Separation of water and salt from seawater by reverse osmosis across charged membranes", Asahi Garasu Kogyo Gijutsu Shoreikai Kenkyu Hokoku, 19, 313-329 (1971).

N15 Nusbaum, I., J.E. Cruver, and J.H. Sleigh, Jr., "Reverse osmosis - new solutions and new problems", AIChE Symp. Series, 68(124), 270-282 (1972).

N16 Nusbaum, I., J.H. Sleigh, Jr., and S.S. Kremen, "Study and experiments in waste water reclamation by reverse osmosis", Water Pollut. Cont. Res. Series No. 17040---05/70, U.S. Dept. of the Int., FWQA, (1970).

O1 Ohya, H. and S. Sourirajan, "Reverse osmosis separation of urea in aqueous solutions using porous cellulose acetate membranes", Ind. Eng. Chem., Process Design and Development, 8, Jan. (1969).

O2 Ohya, H. and S. Sourirajan, "Some general equations for reverse osmosis process design", Al. Chem. Eng. Jour. 15(6), 829-836, Nov. (1969).

O3 Okey, R.W., "Phosphorus removal in membrane waste water treatment", U.S. Patent 3, 398, 088 (1968).

O4 Okey, R.W., "The Application of membranes to sewage and waste treatment", IN: Water Quality Improvement by Physical and Chemical Processes, Univ. of Texas Press, 326-338 (1970).

O5 Okey, R.W., and P.L. Stavenger, "Membrane Technology: A progress report", Ind. Water Eng., 4, 36 (1967).

O6 Okey, R.B., "The treatment of industrial wastes by pressure-driven membrane processes", Chapter XII in "Industrial processing with membranes", R. Lacey and S. Loeb, editors, Wiley, N.Y. (1972).

O7 Ossowski, J., "Effect of flocculation on the effectiveness of electroosmotic drainage of lime sludges", Pr. Nauk. Inst. Geotech. Politech. Wroclaw., 11, 63-38 (1972).

O8 Osterhoudt, H.W., "Transport properties of Eastman cellulose acetate membranes. Influence of diffusant size and shape on permeability", J. Appli. Polym. Sci., 15(3), 597-606 (1971).

O9 O'Sullivan, A.C., "Whey processing by reverse osmosis ultrafiltration and gel filtration", Daily Indus., 636, November (1971).

O10 Otten, G. and G.D. Brown, "Reverse osmosis removal efficiencies of bacteria and pyrogens in water treatments", American Laboratory, 49, Dec. (1973).

P1 Pakalnins, A., and L. Ailick, "Water treatment by reverse osmosis", Eng. J. (Montreal), 54(3), 14-16 (1971).

P2 Palmer, D.J., "Water-removal of soluble contaminants", Australian Chemical Engineering, 13(1-2), 25-33, Jan.-Feb. (1972).

P3 Parkhurst, J.D., and F.D. Dryden, "Removal of dissolved organics and inorganics from the activated sludge plant effluent", Jour. San. Engg. Div., ASCE, 96(SA1), 35 (1970).

P4 Paul, D.R. and O.M. Ebra-Lima, "The mechanism of liquid transport through swollen polymer membranes", J. of Appl. Poly. Sci., 15, 2199-2210 (1971).

P5 Paul, D.R. and O.M. Ebra-Lima, "Pressure-induced diffusion of organic liquids through highly swollen polymer membranes", J. of Appl. Poly. Sci., 14(9), 2201-24 (1970).

P6 Peri, C., C. Pompei and F. Rossi, "Process optimization in skim milk protein recovery and purification by ultrafiltration", J. Food Sci., 38(1), 135-140 (1973).

P7 Perona, J.J., T.W. Pickel and K.A. Kraus, "Hyperfiltration studies XVIII. The optimization of two-stage plants for desalination of brackish waters", Desalination, 8(1), 73-91 (1970).

P8 Perona, J.J. and R.S. Dillon, "Multistage hyperfiltration plants for the desalination of brackish waters", Desalination, 11(2), 149-163 (1972).

P9 Perry, E.S., editor, "Progress in separation and purification", 1, Interscience, London (1968).

P10 Pfafflin, J.R., "Water reuse", Kirk-Othmer Encycl. Chem. Technol., 2nd Ed., 22, 116-124 (1970).

P11 Pilato, L.A., L.M. Litz, J.E. McGrath, R.N. Johnson and I.E. Kochevas, "New polymer membrane technology for desalination of seawater by reverse osmosis", OSW-RDPR-73-867, U.S. National Tech. Inf. Service PB-222 996, (1973).

P12 Pitera, E.W. and S. Middleman, "Convection promotion in tubular desalination membranes", Ind. Eng. Chem. Process Development, 12(1), 52-56 (1973).

P13 Pizzino, J.F. and W.L. Adamson, "Investigation of sea-water reverse osmosis membranes for single-pass shipboard desalination systems", NSRDC 27-54, June (1972).

P14 Podall, H.E., "Recent advances in reverse osmosis membranes for desalination", Chem. Eng. Progr. Symp. Ser., 67(107), 260-266 (1971).

P15 Pompei, C., "Reverse osmosis and ultrafiltration. Treatment of food-industry waste waters", Ind. Aliment. Agr. (Fr.), 88(11), 1585-1591 (1971).

P16 Porter, J.J., "Textile waste treatment: Practices, needed research, and federal legislation", Text. Ind. Environ., AATCC, 1-25 (1971).

P17 Porter, M.C., "Membrane ultrafiltration for pollution abatement and by product recovery", AIChE Symp. Ser., 69(129), 100-122 (1973).

P18 Porter, M.C., P. Schratter and P.N. Rigopulos, "Byproducts recovery by ultrafiltration", Ind. Water Eng., 8(6), 18-24 (1971).

P19 Porter, M.C. and A.S. Michaels, "Applications of membrane ultrafiltration to food processing", Proceedings, Third International Congress of Food Science and Technology, Washington, D.C., 9-14 August (1970). (Institute of Food Technologists, Chicago).

P20 Porter, M.C. and A.S. Michaels, "Food applications for membrane ultrafiltration", Food Product Development, Feb.-Mar. (1971).

P21 Porter, M.C. and A.S. Michaels, "Membrane ultrafiltration", Chem. Tech. 248, April (1971).

P22 Porter, M.C. and A.S. Michaels, "Membrane ultrafiltration, Part 3", Chem. Technol, July issue, 440-445 (1971).

P23 Porter, M.C. and A.S. Michaels, "Membrane ultrafiltration, Part 4. Application of processing vegetable food and beverages", Chem. Tech., 633, October (1971).

P24 Porter, M.C. and A.S. Michaels, "Membrane ultrafiltration, Part 5. A useful adjunct for fermentative and enzymatic processing of foods", Chem. Tech., 56, Jan. (1971).

P25 Porter, M.C., "Ultrafiltration of colloidal suspensions", Amicon Corporation Technical Bulletin, (1971).

P26 Porter, W.L., J. Siciliano, S. Krulick and E.G. Heisler, "Reverse osmosis: Application to potato starch factory waste effluents", Membrane Sci. Technol: Ind., Biol. Waste Treat. Proces., Flinn, J.E. (Ed.), Plenum Press, N.Y., 220-230 (1970).

Q1 Quinn, R.M., R.S. Hamilton, J.R. Anderson and C.O. Weiss, "Some economic factors relating to the use of reverse osmosis and ion exchange for the treatment of water and waste-water", AIChE Symp. Series, 68(124), 262-269 (1972).

R1 Radovan, K., "Operating history of a 324,000 gpd reverse osmosis plant", Industrial Water Engineering, 10(3), 28-35 (1973).

R2 Ralls, J.W., "Treatment of waste streams from food processing", Report of Conference on Reverse Osmosis in Food Processing, Report No. ARS 74-51 (1969).

R3 Rauzen, F., et al., "Operation experience of automatized pilot installation for treatment of effluents by electrodialysis", Report A/Conf. 49/P427, (English), Available Dep. NTIS, U.S.A. (1971).

R4 Rees, E.C. and A.B. Riedinger, "Reverse osmosis and the search for 18 megohm water purity", Electron Packag. Prod., 13(5), 111-126 (1973).

R5 Reeves, G.T., "Nitrogen removal: A literature review", Journal WPCF, 44(10), 1895-1908 (1972).

R6 Reid, C.E. and E.J. Breton, "Water and ion flow across cellulosic membranes", J. of Appl. Poly. Sci., I(2), 133-43 (1959).

R7 Richardson, J.L., G. Segovia, W. Baerg, M.L. Anderson, C.M. Wong, W.S. Gillam, H.E. Podall and L.M. Kindley, "Reverse osmosis tubular module optimization", U.S. Office Saline Water, Res. Develop. Progr. Rep. 455, (1969).

R8 Riedinger, A., I. Nusbaum and J. Cruver, "Reverse osmosis applications in water reuse and recovery", Ind. Water Eng., 9(4), 30-34 (1972).

R9 Riedinger, A.M. and I. Nusbaum, "Reverse osmosis to wastewater reuse", American Society of Mechanical Engineers, ASME Pub. No. 72-PID-17, (1972).

R10 Riedinger, A. ., J.K. Laughlin and R.G. Sudak, "Large reverse osmosis system technology and module development", Office Saline Water Report, OSW-PR-341, Contract DI-14-01-0001-929, June (1968).

R11 Riley, R.L., G. Hightower and C.R. Lyons, "Preparation, morphology, and transport properties of composite reverse osmosis membranes for sea water desalination", Reverse Osmosis Membrane Res., 437-56, (1972).

R12 Riley, R.L., H.K. Lonsdale and C.R. Lyons, "Composite membranes for seawater desalination by reverse osmosis", J. Appli. Polym. Sci., 15(5), 1267-1276 (1971).

R13 Riley, R.L., U. Merten and J.O. Gardner, "Replication electron microscopy of cellulose acetate osmotic membranes", Desalination, 1, 30 (1966).

R14 Rivet, P., "Ultrafiltration applied to the treatment of effluents", Ind. Miner., Mineralurgie, (1), 41-45 (1973).

R15 Roberts, R.M., and L.E. Gressing, "Development of economical methods of boron removal from irrigation return waters", U.S. Office Saline Water, Res. Develop. Progr. Rep., OSW-PR-579, (1970).

R16 Rodziller, I.D. and Y.N. Golovenkov, "Purification of waste waters by reverse osmosis", Zh. Vses. Khim. Obshchest., 17(2), 184-8 (1972).

R17 Rozelle, L.T., J.E. Cadotte, A.J. Senechal, W.L. King and B.R. Nelson, "Tubular ultrathin cellulose acetate membranes for water desalination", Reverse Osmosis Membrane Research, 419-435 (1972).

R18 Rozelle, L.T., J.E. Cadotte and D.J. McClure, "Ultrathin cellulose acetate membranes for water desalination", Appl. Polym. Symp., (13), 61-71 (1970).

R19 Rozelle, L.T., "Ultrathin membranes for treating metal finishing effluents by reverse osmosis", Water Poll. Cont. Res. Series 12010 DRH 11/71, EPA·WQO, U.S., (1971).

R20 Rozelle, L.T., R.J. Petersen and R.D. Corneliussen, "Ultrathin membranes for hemodialysis applications", ACE Symposium, Membranes from Cellulose and Cellulose Derivatives, Minneapolis, Applied Polymer Symposium No. 13 (A.F. Turbak, Ed.), Interscience Publishers (1970).

R21 Rubenstein, S.H., J. Fenters, H. Orgach, N. Shuber, J. Reed and E. Molloy, "Viruses in metropolitan waters: Concentration by polyelectrolytes, freeze concentration and ultrafiltration", J. Am. Water Works Assoc., 65(3), 200-202 (1973).

R22 Ruebsamen, W.R., "Electrodialysis water treatment", Military Engineer, 63(411), 34 (1971).

R23 Rybak, I., "Separation of water-phenol mixtures by reverse osmosis", Neftepererab. Neftekhim. (Moscow), 74(3), 41-3 (1974).

S1 Saltonstall, C.W., J.A. Hunter, W.S. Gillam and H.E. Podall, "Development of new and improved cellulose ester reverse osmosis membranes", U.S. Office Saline Water, Res. Develop. Progr. Rep. 434, (1969).

S2 Saltonstall, C.W., Jr. and H.F. Shuey, "In-situ and dynamically-formed reverse-osmosis membranes", Office Saline Water Report, OSW-RDPR-71-730, Dec. (1971). Contract DI-14-30-2671.

S3 Saravacos, G.D. and H.D. Iredale, "Physical treatments of food processing waste waters", N.Y. Food Life Sci. Bull., 12, 1-5 (1971).

S4 Sarbolouki, M.N. and I.F. Miller, "On pore flow models for reverse osmosis desalination", Desalination, 12(3), 343-359 (1973).

S5 Schrantz, J., "Rock Island arsenal's zero discharge", Ind. Finish. (Wheaton, Ill.), 49(6), 38-45 (1973).

S6 Schubert, P. and V.H. Edwards, "Concentration and analysis of pesticides and other recalcitrant molecules in water supplies by ultrafiltration (reverse osmosis)", U.S. Nat. Tech. Inform. Serv., P.B. Rep. 214744/5, (1972).

S7 Schultz, J., A. Riedinger, H. McCraken, et al, "Brackish well water reverse osmosis tests at Midland, Fort Stockton and Kermit, Texas", OSW, Rep. No. 237 (1967).

S8 Scott, H., F.L. Serafin and P.L. Kronick, "Polyimidazopyrrolone reverse osmosis membranes", J. Polym. Sci., Part B, 8(8), 563-571 (1970).

S9 Selldorff, J.A., "Ultrafiltration", Pollution Eng., 2(1), 30 (1970).

S10 Sharples, A., "The purification of water by reverse osmosis", Filtr. Separation, 4(3), 211 (1967).

S11 Shenouda, F., "Procedures for water desalination, sewage treatment and concentrating aqueous solutions", Wasser, Luft Betr, Issue Sonderh., Pro. Aqua-Pro Vita, 27-34 (1971).

S12 Sheppard, J.D., and D.G. Thomas, "Control of concentration polarization and arrest of fouling of cellulose acetate hyperfiltration membranes by high axial velocity", Appl. Polym. Symp., (13), 121-138 (1970).

S13 Sheppard, J.D. and D.G. Thomas, "Increased polarization caused by films covering hyperfiltration membranes", AIChE Journal, 17(4), 910-915 (1971).

S14 Sheppard, J.D., "Some factors affecting the performance of hyperfiltration membranes", Oak Ridge National Library Report, ORNL-TM-3296, May (1971). Contract W-7405-ENG-26.

S15 Shields, C.P., "Reverse osmosis for municipal water supply", Water and Sewage Works, 119(1), 64, January (1972).

S16 Shor, S.M. and G. Thodos, "Reverse osmosis applied to recovery of water from aqueous salt solutions", J. Appl. Chemistry, 18(11), 322-6, Nov. (1968).

S17 Shor, A.J., et al, "Hyperfiltration concentration polarization in tubular systems with dynamically formed membranes", Ind. & Eng. Chem. Fundamentals, 7, 44 (1968).

S18 Short, W., R.T. Skrinde, and D.G. Newton, Jr., "Low-pressure ultrafiltration systems for wastewater contaminant removal", Membrane Sci. Technol: Ind., Biol. Waste Treat. Proces., Flinn, J.E. (Ed.), Plenum Press, N.Y., p. 188-195 (1970).

S19 Sieber, C.W., "Evaluation of reverse osmosis on bare base waste water and Potomac River water", U.S. Army Mobility Equipment Research and Development Laboratories, Fort Belvoir, Va., Report dated August (1969).

S20 Siegerman, H., "Applications of electrochemistry to environmental problems", Chem. Technol., 672-679 (1971).

S21 Sinskey, A.J., G.C.Y. Chu and D.I.C. Wang, "Concentration and purification of viruses by ultrafiltration", Chem. Eng. Progr., Symp. Ser., 67(108), 75-79 (1971).

S22 Skrinde, R.T., W.L. Short and D.J. Smola, "Reverse osmosis treatment of wastewaters", Appl. Polym. Symp., (13), A.F. Turbak (Ed.), Interscience Pub. 323-334 (1970).

S23 Sleigh, J.H. and S.S. Kremen, "Acid mine waste treatment using reverse osmosis", Water Pollut. Contr. Res. Series, 14010 DYG 11/70, EPA.WQO, U.S. (1970).

S24 Smith, C.V., Jr. and D. DiGregorio, "Ultrafiltration water treatment", Proceedings Membrane Science and Tech.: Ind., Biol. and Waste Treatment Processes Symposium, Columbus, Ohio, (1970). Sponsored by Battele Memorial Institute, Plenum Press, N.Y.

S25 Smith, C.V., D. DiGregario and P.M. Talcott, "Use of ultrafiltration membranes for activated-sludge separation", Eng. Bull. Purdue Univ., Eng. Ext. Ser., p. 1300-1310, (1969).

S26 Smith, C.V., "The use of ultrafiltration for pre-treatment of industrial wastes", Technical Aspects of Joint Waste Treatment, Municipal/Industrial Institute. Proceedings. Litsky, W., Gummer, H.B., and Kreplick, R. (Eds.). (Held in Farmingdale, Mass., March 5-6 (1969)). Sponsored by Univ. of Massachusetts, Technical Guidance Centre for Industrial Water Pollution Control, Amherst and Associated Industries of Massachusetts, 119-139 (1969).

S27 Smith, J.K., F. Morton, E.P. Klein, C.M. Wong, W.S. Gillam and H.E. Podall, "Study of oriented cellulose membranes for reverse osmosis and the relationship between morphology and salt rejection", U.S. Office Saline Water, Res. Develop. Progr. Rep. 507 (1970).

S28 Smith, J.N., "Renovation of municipal wastewater by reverse osmosis", Water Pollution Control Research Series No. 17040 --- 05/70, EPA.WQO, U.S., (1970).

S29 Smith, S.E., "Industrial wastes. Plating and cyanide wastes", J. Water Pollut. Contr. Fed., 44(6), 1100-1104 (1972).

S30 Snoeyink, V.L. and F.I. Marcus, "USAF mobility program water treatment system", U.S. National Technical Inf. Service, AD-766 656, (1973).

S31 Sonoyama, T., "Recovery of products from fermentation processes by ultrafiltration", M.S. thesis, Dept. of Nutrition and Food Science, M.I.T., June (1968).

S32 Sorber, C.A., J.F. Malina Jr., and B.P. Sagik, "Virus rejection by the reverse osmosis-ultrafiltration processes", Water Res., 6(11), 1377-1388 (1972). Also avail. Univ. Microfilms, Ann Arbor, Mich., Order No. 72-19, 674 (1971).

S33 Sourirajan, S., "Reverse osmosis", Academic Press, N.Y., (1970).

S34 Sourirajan, S., "Reverse osmosis separation and concentration of sucrose in aqueous solutions using porous cellulose acetate membranes", Ind. Eng. Chem., Process Design and Development, 6, 154 (1967).

S35 Sourirajan, S., "The mechanism of demineralization of aqueous sodium chloride solutions by flow, under pressure, through porous membranes", I&EC Fundamentals, 2(1), 51-55 (1963).

S36 Spatz, D.D., "Reclaiming valuable metal wastes", Pollut. Eng., 4(1), 24-26 (1972).

S37 Spatz, D.D., "Reclamation and reuse of waste products from food processing by membrane processes", AIChE Symp. Ser., 69(129), 89-99 (1973).

S38 Spatz, D.D., "Reverse osmosis for reclamation and reuse of chemical and metal waste solutions", R.H.L. Howe (Ed.), Hazardous Chem. Handling and Disposal. Proc. Symp., 2nd, p. 58-80 (1971).

S39 Spatz, D.D., "Electroplating waste water processing with reverse osmosis", Prod. Finish. (Cincinnati), 36(11), 79-89 (1972).

S40 Spatz, D., "Chromium waste treatment", Technical Bulletin, Osmonics, Inc., Minneapolis, Minn.

S41 Spatz, D., "Reverse osmosis reclamation systems for the plater", Technical Bulletin, Osmonics, Inc.

S42 Spiegler, K.S., "Study of mass transfer in membrane processes", Office Saline Water Report, OSW-PR-613 (1970). Contract DI-14-01-001-1295.

S43 Spiewak, I., "Survey of desalting processes for use in wastewater treatment", Proceedings, 9th Annual Environmental and Water Resources Engg. Conf.; Thackston, E.L. and Benedict, B.A. (Eds.).

S44 Srinivasan, S. and C. Tien, "Finite difference solution for reverse osmosis in turbulent flow", Desalination, 7(1), 51-74 (1969).

S45 Srinivasan, S. and C. Tien, "Reverse osmosis in a curved tubular membrane duct", Desalination, 9(2), 127-139 (1971).

S46 Srinivasan, S. and C. Tien, "Simplified method for the prediction of concentration polarization in reverse osmosis operation for multi-component systems", Desalination, 7(1), 133-145 (1969).

S47 Srinivasan, S. and C. Tien, "Natural convection effect in reverse osmosis", Desalination, 10(3), 273-286 (1972).

S48 St. Amant, P.P. and L.A. Beck, "Methods of removing nitrates from water", J. of Africultural and Food Chemistry, 18(5), 785 (1970).

S49 Stana, R.R., "Improving the salt rejection of semipermeable, reverse osmosis membranes with detergent additives", U.S. Patent 3721623, (1973).

S50 Stavenger, P.L., "Putting semipermeable membranes to work", Chem. Eng. Progress, 67(3), 30 (1971).

S51 Stavenger, P.L., "Novel applications of industrial semipermeable membranes", 3rd Joint Meeting of AIChE and Instituto Mexicano de Ingenieros Quimcos, Denver, Colorado, August 30 (1970).

S52 Stern, S.A., "Gas permeation processes", Chapter 13 in "Industrial processing with membranes", R.E.Lacey and S. Loeb, editors, Wiley (1972).

S53 Stone, R. and Co., Inc., Los Angeles, Calif., "The Wrightsville beach, North Carolina, pilot plant testing program to evaluate sea water pretreatment methods for reverse osmosis plants", OSW., U.S. National Technical Information Service, PB-223 582, (1973).

S54 Stone, R. and Co., Inc., Los Angeles, Calif., "The Chula Vista, California, pilot plant testing program to evaluate seawater pretreatment methods for reverse osmosis", OSW, U.S. National Technical Information Service, PB-223 594, (1973).

S55 Strathmann, H., P. Scheible and R.W. Baker,"Rationale for the preparation of Loeb-Sourirajan-type cellulose acetate membranes", J. Appl. Polym. Sci., 15(4), 811-828 (1971).

S56 Strathman, H., "Control of concentration polarization in reverse osmosis desalination of water", Office Saline Water Report, OSW-PR-336, April (1968). Contract DI-14-01-0001-964.

S57 Subcasky, W.J., C.M. Wong, W.S. Gillam, H.E. Podall and L.M. Kindley, "Improvement of tubular cellulose acetate membranes by feed additives", U.S. Office Saline Water, Res. Develop. Progr. Rep. 532 (1970).

S58 Subcasky, W.J., G. Segovia, C.M. Wong, W.S. Gillam, H.E. Podall, and L.M. Kindley, "Determination of the surface and colloidal conditions which can lead to high salt rejection reverse osmosis polymer membranes", U.S. Office Saline Water, Res. Develop. Progr. Rep. 466 (1969).

S59 Sudak, R.G., J.A. Hunter, W.F. Savage, and K.C. Channabasappa, "Test of 10,000 gpd reverse osmosis (spiral module) pilot plant San Diego, California", U.S. Office Saline Water, Res. Develop. Progr. Rep. 453 (1969).

S60 Sudak, R.G. and F.R. Lepper, "100-gpd portable reverse osmosis unit", Gulf General Atomic, Inc., Descriptive note; final report, GA-8448, Feb. (1968).

S61 Suzuki, A., "Selection and uses of waste-water treatment equipment for food-processing plants. Use of reverse osmosis for waste water treatment at food-processing plants", Shokuhin Kogyo, 15(6), 73-81 (1972).

S62 Sweet, B.H. and R.D. Ellender, "Electo osmosis a new technique for concentrating viruses from water", Water Res., 6(7), 775-779 (1972).

S63 Sweet, B.H. et al, "Concentration of virus from water by osmosis ultrafiltration. I - Biological aspects", Water Research New York, 5(10), 823-829, Oct. (1971).

S64 Swope, G, "Westinghouse enters the reverse osmosis field", Water and Sewage Works, Chicago, 118(8), 252-253, Aug. (1971).

S65 Sword, B.R., "Desalination of agricultural tile drainage", U.S. Nat. Tech. Inform. Serv., PB Rep. 213890/2, (1971).

T1 Tang, T-L., "Movement of lead and mercury compounds in DuPont permasep reverse osmosis nylon membranes", Eng. Thesis, University of Iowa, Iowa, (1972).

T2 Testa, L.A., and P.F. Bruins, "Cellulose acetate membranes for wastewater purification", Modern Plastics, 45(9), 141 (1968).

T3 Thau, G., R. Bloch and O. Keden, "Water transport in porous and non-porous membranes", Desalination, 1, 129-138 (1966).

T4 Thielema, H., "Identification and removal of substances with intense odor and taste in ground water after ultrafiltration at the Roesser-Merseburg waterworks", Zeitschrift Fur Chemie, 9(8), 314-315 (1969).

T5 Thomas, D.G., W.L. Griffith and R.M. Keller, "The role of turbulence promoters in hyperfiltration plant optimization", Desalination, 9(1), 33-50 (1971).

T6 Thomas, D.G., P.H. Hayes, W.R. Mixon, J.D. Sheppard, W.L. Griffith and R.M. Keller, "Turbulence promoters for hyperfiltration with dynamic membranes", Environ. Sci. Technol., 4(12), 1129-2236 (1970).

T7 Thomas, D.G. and W.R. Mixon, "Effect of axial velocity and initial flux on flux decline of cellulose acetate membranes in hyperfiltration of primary sewage effluents", Ind. Eng. Chem. Process Res. Dev., 11(3), 339-343 (1972).

T8 Thomas, D.G., W.R. Mixon and P.H. Hayes, "Support for dynamic membrane", Patent application, U.S. National Tech. Inf. Service PAT-APPL-383, 243 (1973).

T9 Titow, W.V., "Desalination by reverse osmosis", Brit. Patent 1305385, (1973).

T10 Titus, J.B., "Reverse osmosis bibliography: Abstracted and indexed", Plastics Technical Evaluation Center, New Jersey, PLASTEC Report R45 (1973).

T11 Treille, P., "Reverse osmosis desalting of water", Fr. Patent 2126586 (1972).

T12 Treille, P., "Reverse osmosis", Effluent and Water Treatment Jour., Focus on Degremont Laing., pp 22-23, (1972).

T13 Tsao, C.K., "Concentration polarization at the phase boundary of an external tubular reverse osmosis membrane", Desalination, 8(2), 243-258 (1970).

T14 Tsao, C.K., "Salt concentration at the phase boundary of an external tubular reverse osmosis", Final Report, Contract N00161-68-R-o182; Project SF-013-01-01; Task 11275, Dec. (1968).

T15 Tuwiner, S.B., "Diffusion and Membrane Technology", Reinhold New York, (1962).

U1 Underwood, J.C., "Concentration of Maple Sap", U.S. Dept. of Agriculture Report ARS-74-51 (1969).

U2 Underwood, J.C. and C.O. Willits, "Operation of a reverse osmosis plant for the partial concentration of maple sap", Food Technol., 23(6), 79-82 (1969).

V1 VanOss, C.J. and P.M. Bronson, "Removal of IgM from serum by ultrafiltration", Anal. Biochem., (36), 464 (1970).

V2 Vieth, W., A.S. Douglas and R. Bloch, "Membrane-water structural interactions in reverse osmosis transport", J. Macromol. Sci.- Phys., B3(4), 737-749 (1969).

V3 Vofsi, D., and O. Kedem, "Hyperfiltration in polyelectrolyte membranes", Weizmann Inst. of Sci., O.S.W. R&D Prog. Rep. No. 787 (PB 215 173/6), 48, (From Govt. Rep. Ann., 73(8), 25 April (1973)).

V4 Vos, K.D., et al., "Storage, disinfection and life of cellulose acetate reverse osmosis membranes", Desalination, 5, 157 (1968).

V5 Vos, K.D., F.o. Burris, Jr., "Drying cellulose acetate reverse osmosis membranes", Ind. Eng. Chem., Product Research and Development, 8(1), 84-9 (1969). Also in OSW R&D Progress Report No. 348, Contract No. 14-01-0001-767, November (1967).

W1 Wallace, R.A. and R.J. Gable, "The electret effect in cellulose acetate reverse osmosis membranes", Polymer Eng. and Science, 14, 92 (1974).

W2 Wang, D.I.C., T. Sonoyama and R.I. Mateles, "Enzyme and bacteriophage concentration by membrane ultrafiltration", Anal. Biochem., 26, 277 (1968).

W3 Wang, D.I.C., A.J. Sinskey and T. Sonoyama, "Recovery of biological materials through ultrafiltration", Biotech. and Bioeng., XI, 987 (1969).

W4 Wang, D.I. et al, "Enzyme processing with ultrafiltration membranes", in "Membrane science and technology", J.E. Flynn, (Ed.), Plenum Press, New York, (1970).

W5 Washingt, D.R. and L.S. Clesceri, "Ultrafiltration for the control of recycled solids in a biological system", Amer. Chem. Soc., Div. Water, Air Waste Chem., Gen. April issue, 196-204 (1969).

W6 Watson, E.R., J.A. Hunter, W.F. Savage and K.C. Channabasappa, "Field operation of a mobile reverse osmosis pilot plant", U.S. Office Saline Water, Res. Dev. Progr. Rep. 429 (1969).

W7 Watson, E.R., et al, "Operation of a 50,000 gpd portable reverse osmosis pilot plant", Office Saline Water Report, OSW-PR-430, May (1969). Contract DI-14-01-0001-930.

W8 Watson, E.R., "Design and fabrication of a 50,000 gpd portable reverse osmosis pilot plant", Office Saline Water Report, OSW-PR-431, May (1969). Contract DI-14-01-0001-930.

W9 Weiner, R., "Reverse osmosis and electrodialysis", Galvanotechnik, 63(7), 614-619 (1972).

W10 Weinstein, R.H., "Water recycling for domestic use", Astronaut Aeronaut, 10(3), 44-51, Mar. (1972).

W11 Weissman, B.J., C.V. Smith, Jr., and R.W. Okey, "Performance of membrane systems in treating water and sewage", Chem. Eng. Progr. Symp. Ser., 64(90), 285-290 (1968).

W12 Wells, G.W., W. Wong and D.F. Putnam, "Design considerations for space mission wash water processing by reverse osmosis", ASME Paper 73-ENAS-3, (1973).

W13 Westbrook, G.T., "The emergence of membrane technology", AIChE Symp. Series, 68(124), 283-293 (1972).

W14 Williams, F.A., T.J. Hendricks and M.K. Liu, "Boundary layer flow problems in desalination by reverse osmosis", Office Saline Water Report, OSW-PR-622, Dec. (1970). Contract DI-14-01-0001-951.

W15 Williams, R.H., et al, "Design integrity and performance characteristics of helical tubular module elements in reverse osmosis plants", Int-OSW-RDPR-73-871, U.S. National Tech. Inf. Service, PB-223 119/9, (1973).

W16 Williams, R.H., et al, "Investigation of the effect of coatings on the failure mechanisms of fiberglass yarn in tubular reverse osmosis supports", Int-Osw-RDPR-73-884, U.S. Nat. Tech. Inf. Ser., PB-223 382/3, (1973).

W17 Willits, C.O., J.C. Underwood and U. Merten, "Concentration by reverse osmosis of maple sap", Food Technology, 21, 24-26 (1967).

W18 Wilmoth, R.C. and R.D. Hill, "Mine drainage pollution control via reverse osmosis", Mining Eng. (N.Y.), 25(3), 45-47 (1973).

W19 Wilmoth, R.C., D.G. Mason and M. Gupta, "Treatment of ferrous iron acid mine drainage by reverse osmosis", U.S. Nat. Tech. Inform. Serv., PB. Rep. 213721/7, (1972). Also in Symp. on Coal Mine Drainage Res., 4th, held in Pittsburgh, Pa., April 26-27, (1972).

W20 Wilmoth, R.C., "Applications of reverse osmosis to acid mine drainage treatment", Environmental Protection Tech. Series No. EPA-670/2-73-100, U.S.-EPA, (1973).

W21 Wiley, A.J., G.A. Dubey, J.M. Holderby and A.C.F. Ammerlaan, "Concentration of dilute pulping wastes by reverse osmosis and ultrafiltration", J. Water Pollut. Contr. Fed., 42(8), Pt. 2, R279-289 (1970).

W22 Wiley, A.J., K. Scharpf, I. Bansal and D. Arps, "Reverse osmosis concentration of spent liquor solids in pressates from high density pulps", TAPPI Environ. Conf., 149-162 (1972).

W23 Wiley, A.J., A.C.F. Ammerlaan and G.A. Dubey, "Application of reverse osmosis to processing of spent liquors from the pulp and paper industry", OSW Res. Conf. on Reverse Osmosis, San Diego, Calif., February 13-15 (1967). Also: TAPPI 50(9), 455-60 (1967).

W24 Wiley, A.J., G.A. Dubey and I.K.Bansal, "Reverse osmosis concentration of dilute pulp and paper effluents", U.S. Environmental Protection Agency, Water Quality Office, Wash., D.C., Water Pollution Control Research Series No. 12040 EEL, 367 pages, Feb. (1972).

W25 Winograd, Y. and A. Solan, "Concentration build-up in reverse osmosis in turbulent flow", Desalination, 7(1), 97-109 (1969).

W26 Witmer, F.E., "Reusing waste water by desalination", Environ. Sci. Techno., 7(4), 314-318 (1973).

W27 Wright, J.B., "Reverse osmosis. A new tool for water purification", Westinghouse Eng., 31(4), 108-113 (1971).

W28 Wutschel, A., "New water purification method. Reverse osmosis", Oberflaeche-surface, 21(3), 42-46 (1972).

W29 Wydeven, T. and M.I. Leban, "Purification of contaminated water by filtration through porous glass", Ames Res. Center, NASA Tech. Brief, B72-10412, Sept. (1972).

Y1 Yasuda, H., and C.E. Lamaze, "Morphology of modified cellulose acetate membranes", Appli. Poly. Symp., (13), 157-67 (1970).

Y2 Yasuda, H., and C.E. Lamaze, "Salt rejection by polymer membranes in reverse osmosis - I", J. Poly. Sci., Part A-2, Polym. Phys., 9(9), 1537-1551 (1971).

Y3 Yasuda, H., C.E. Lamaze and A. Schindler, "Salt rejection by polymer membranes in reverse osmosis - II", J. Poly. Sci., Part A-2, Polym. Phys. 9(9), 1579-1590 (1971).

Y4 Yasuda, H., C.E. Lamaze, C.M. Wong, and W.S. Gillam, "Improved membranes for reverse osmosis", U.S. Office Saline Water, Res. Develop. Progr. Rep. 473, (1969).

Y5 Yasuda, H., A. Peterlin, C.K. Colton, K.A. Smith and E.W. Merrill, "Permeability of solutes through hydrated polymer membranes; Part III. Theoretical background for the selectivity of dialysis membranes", Die Makromolekulare Chemie, 126, 177-86 (1969).

Y6 Yasuda, H., C.E. Lamaze and A. Peterlin, "Diffusive and hydraulic permeabilities of water in water-swollen polymer membranes", J. of Poly. Sci., Part A-2, 9, 1117-1131 (1971).

Y7 Yasuda, H. and A. Peterlin, "Diffusive and bulk flow transport in polymers", J. of Applied Poly. Sci., 17, 433-442 (1973).

Y8 Yasuda, H. and C.E. Lamaze, "Preparation of reverse osmosis membranes by plasma polymerization of organic compounds", J. of App. Poly. Sci., 17, 201-222 (1973).

Y9 Young, K.G., "Desalting technology in pollution control problems", J. Amer. Water Works Assn., 63(1), 21-4 (1971).

SUBJECT INDEX

SUBJECT INDEX

A. Acid Mine Drainage:
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Boundary Layer: (see Concentration Polarization)

C. Chemical Recovery: (see also Wastewater Treatment)
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G15	G19	G33	G34	H30	J10	J11
K5	K17	K30	K44	L6	L10	L15
L16	L27	L34	M2	M8	M15	M16
M36	M47	M60	N14	P7	P8	P11
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Detergent: (see Sewage Treatment/Nutrients and Phosphates)

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Dye: (see Textile Wastes)

E. Economics: (see also Simulation)

AN11 B7 B23 C11 C12 C20 C37
D12 D25 E11 F3 F4 F5 F7
G30 G38 H11 H12 H36 L2 L15
L16 L17 L22 L33 M15 M56 M70
Q1 R7 R15 W12

Electron Micrographs: (see Membrane Development)

Electro-osmosis/Electrodialysis:

AN12 AN13 AN23 B45 B58 B60 C14
D11 D22 E1 G35 G37 H15 H36
K30 L3 N12 R3 R22 S20 S62
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F. Flux Loss: (see Cleaning)

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G22 H33 L11 L46 M32 M67 N9
O9

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B4	B50	B62	C7	C25	F25	G7
G8	G38	G39	G40	G45	H20	K9
K35	P7	P8	S12	S13	S14	S17
T5	T6	V3				

I. Industrial Waste Water: (see Wastewater Treatment)

Inorganic Chemicals: (see Metals and Desalination/Demineralization)

Ion Exchange with Reverse Osmosis:

A14 D22 Q1

M. Mathematical Modelling: (see Simulation)

Medical: (see Special Applications and Concentration/Separation)

Membrane Development:

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AN30	AN55	B5	B6	B9	B10	B11
B12	B31	B32	B56	B57	C2	C4
C19	C21	C22	C27	C28	C29	D7
D14	D15	D19	F1	F11	F23	G9
G12	G13	H5	H10	H29	H31	H32
J11	K6	K10	K11	K12	K13	K15
K22	K28	K32	K33	K43	K44	L7
L12	L23	L24	L32	L41	L43	M2
M4	M5	M9	M12	M26	M34	M35
M36	M38	M39	M40	M53	M63	N7
O7	P11	P14	R11	R12	R13	S1
S2	S8	S27	S33	S49	S55	S57
S58	T2	V3	V4	V5	W1	Y1
Y4	Y8					

Membrane Regeneration: (see Cleaning)

Metals:

AN1	AN3	AN4	AN8	AN42	AN68	D22
D23	G19	G28	G29	G30	H13	I6
L18	M42	M62	N1	N10	N12	R19
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Microorganism: (see Concentration/Separation and Special Application)

Module Designs:

	AN39	AN47	AN59	B21	B23	D9	F14
	G3	G4	G7	G8	G10	G11	G46
	H14	H19	H20	K1	K2	K17	L36
	L37	L45	M10	M29	M53	M55	R10
	S44	S45	S47	S60	S64		
Hollow Fibre	AN17	AN23	AN57	AN58	AN64	AN69	B8
	B42	C17	C23	C31	C32	C36	C38
	D2	G6	L24	L25	M4	M5	M34
	M35	M41	T1				
Plate & Frame	G46						
Spiral Wound	AN14	AN40	AN54	C29	F19	F21	L8
	L9						
Tubular	C21	F6	F12	F15	G39	H2	R7
	R17	S57	T12	T14	W15		

Turbulence Promotors: (see also Concentration Polarization)

G7	P12	T5	T6	T7	T13	T14

Municipal Waste Treatment: (see Sewage Treatment)

N. Nutrient Removal: (see Sewage Treatment/Nutrient)

O. Organic Removal: (see also Chemical Recovery and Wastewater Treatment)

AN13	AN56	D20	D26	G37	H27	M18
M19	M20	M21	M22	M23	M24	M28
M34	M35	M48	O1	P5	R23	

P. Petrochemical Wastes: (see Wastewater Treatment and Chemical Recovery)

Phosphate Removal: (see Sewage Treatment/Nutrients and Phosphates)

Pilot Plants:

Desalination	B46	B52	B55	D6	D8	E12	F13
	F17	F21	H4	M8	M30	M41	R1
	R3	S53	S54	S59	W6	W7	W8
Portable/ Mobile	M15	S30	S60	W6			
Shipboard	C1	H35	P13				
Waste Treatment	B60	G43	K4	K23	L9	L26	
Miscellaneous	C12	C35	F17	G23			

R. Radioactive Wastes: (see Chemical Recovery and Wastewater Treatment)

S. Sewage Treatment:

Raw, Primary,	AN5	AN49	AN50	AN66	B17	B18	B25
Secondary,	B26	B27	B31	B63	C15	C25	C34
Tertiary	C41	D4	D16	E4	F8	G13	G26
	G27	H6	H7	I3	J5	J6	K36
	K41	L29	P3	S25	T7	W5	
Sludge	G35	G47	H7	J5	J6	P3	S25
	W5						
Nutrients & Phosphates	AN37	B59	C26	C34	H15	H17	K8
	K9	O3	R5				

Simulation:

AN23	B6	B7	G1	K20	K27	L35
M68	O2	S42	W12			

Special Applications:

B30	B34	B36	B65	C1	C31	C32
G15	G23	G32	G34	G35	G42	H18
H20	H34	H37	H21	K43	L13	L30
M60	P13	R15	R20	S6	S30	S51
S52	V1	W12				

Steel Mill Waste: (see Wastewater Treatment and Metals)

Wastewater Treatment (continued):

D27	D28	E3	E10	F7	F9	F10
F26	G2	G5	G18	G24	G26	G27
G28	G44	H13	H27	H28	I2	I4
K6	K7	K9	K23	K26	K34	K37
K38	K39	K45	L1	L4	L5	L18
L20	L21	L39	L40	L42	L49	M3
M6	M7	M11	M17	M18	M19	M20
M21	M22	M23	M24	M28	M31	M33
M34	M49	M50	M52	M66	M69	N15
N16	O4	O5	O6	P26	R3	R9
R14	R16	S5	S11	S18	S22	S26
S28	S29	S36	S38	S39	S40	S41
S43	S50	S51	T2	T10	T12	W11
W28	Y9					

Water Treatment:

AN41	AN42	AN43	C5	C6	C9	C10
C13	C20	C24	E7	F3	F4	F5
F18	F20	G1	G31	G32	H8	H13
H26	H27	H28	H38	J4	K37	K42
K46	L19	L50	M25	M28	M58	M59
M64	N13	P1	P2	P9	P10	R4
R8	S10	S15	S19	S30	T4	T15
W10	W27	W29				

T. Textile Wastes:

A16 B49 P16

Theory and Mechanism of Reverse Osmosis:

A1 A2 AN25 B5 B6 B20 B33
B38 D7 E9 F23 F24 G9 G16
G17 H9 J3 J13 K5 K33 L1
L4 L5 L43 L44 M20 M21 M22
M23 M24 M27 M37 M51 P4 P5
R6 R13 S4 S35 S55 T3 V2
W1 Y2 Y3 Y5 Y6 Y7

U. Ultrafiltration: (see also Hyperfiltration)

AN18 AN27 AN63 B1 B2 B3 B4
B34 B36 B38 B39 B43 B48 B62
B64 C16 C33 C38 E8 F2 F16
G13 G21 G36 H7 H18 H29 J2
L14 L30 M31 M54 N11 P6 P17
P18 P20 P21 P22 P23 P24 P25
R14 R21 S6 S9 S21 S24 S31
S32 S42 S63 V1 W3 W4 W5

W. Wastewater Treatment:

A3 A14 AN8 AN9 AN11 AN19 AN26
AN28 AN40 AN49 AN52 AN61 AN64 AN65
B8 B14 B15 B16 B22 B30 B53
C8 C11 C19 C25 C30 C32 C35
C36 C39 C40 D4 D5 D10 D12

APPENDIX I

COMPANIES SELLING COMMERCIAL REVERSE OSMOSIS OR ULTRAFILTRATION EQUIPMENT

COMPANIES SELLING COMMERCIAL REVERSE OSMOSIS OR ULTRAFILTRATION EQUIPMENT

1. Abcor Inc., 341 Vassar St., Cambridge, Mass. 02139, USA.
2. Aerojet-General Corporation, Envirogenics Co., 9200 East Flair Drive, El Monte, Calif. 91734, USA.
3. Ajax International, Box 4007, Santa Barbara, Calif.93103, USA.
4. Ames Crosta Mills (Canada) Ltd., 105 Brisbane Road, Downsview, Ontario, Canada.
5. Amicon Corporation, 21 Hartwell Avenue, Lexington, Mass.02173, USA.
6. Aqua-Chem (Ajax) Inc., 225 W. Grand Ave., Waukesha, Wis. 53186, USA.
7. Aquanomic Inc., 11809 "J" E. Slauson Avenue, Santa Fe Springs, Calif., USA.
8. Anderson, J.W., Company Limited, Dundas, Ontario, Canada.
9. Better Built Machinery, 441 Market Street, Saddle Brook, N.J. 07662, USA.
10. Benner, R.E., Ltd., 620 Supertest Road, Downsview, Ontario Canada.
11. Bio-Rad Laboratories, 32nd and Griffin Avenue, Richmond, Calif. 94804, USA.
12. Burns and Roe Inc., 700 Kinderkamak Rd., Oradell, New Jersey 07649. USA.
13. Calco, 1120 West Jackson Blvd., Chicago Illinois 60607, USA.
14. Calgon-Havens Systems, 8133 Aero Dr., San Diego, Calif. 92123, USA.
15. Canadian Cabinets Co., 130 Murray St., Montreal 102, P.Q., Canada.
16. Carver-Greenfield Corp., 9 Great Meadow Lane, Hanover, N.J. 07936, USA.
17. Chemapec, 1 Newark Street, Hoboken, N.J. 07030, USA.
18. Continental Water Conditioning Corp., Box 26428, 1013 Wall Street, El Paso, Texas 79926, USA.
19. Cosmodyne Corp., 2920 Columbia St., Torrance, Calif 90509, USA.

20. Crane Co., Cochrane Division, 800 3rd Ave., P.O. Box 191, King of Prussia, P.A. 19406, USA.

21. Crane Canada Ltd., Cochrane Division, 1355 Martin-Grove, Rexdale, Ontario, Canada.

22. Culligan Canada Limited, Sheridan Park, Mississauga, Ont., Canada.

23. Desalination Systems Inc., 1107 West Grant Ave., Escondido, Calif. 92025, USA.

24. Dorr-Oliver Inc., 77 Havenmeyer Lane, Stamford, Conn. 06904, USA.

25. Dow Chemical Co., Membrane Systems, Barstow Bldg., 2020 Dow Centre, Midland, Mich. 48640, USA.

26. E.I. DuPont de Nemours & Co., Wilmington, Del. 19898, USA.

27. Eastman Chemical Co., Kingsport Tenn. 37662, USA.

28. Ecotech Inc., P.O. Box 458, Cardiff, Calif. 92007, USA.

29. Electrohome Ltd., 809 Wellington St. N., Kitchener, Ontario, Canada.

30. Extracorporeal Medical, Royal and Ross Roads, King of Prussia, Pa. 14406, USA.

31. Foxboro Co., Ltd., 707 Dollard Avenue, La Salle 650, Quebec, Canada.

32. Gulf General Atomic, P.O. Box 608, San Diego, Calif. 92112, USA.

33. Illinois Water Treatment Co., 840 Cedar Street, Rockford, Ill. 61105, USA.

34. Ionics, 65 Grove Street, Watertown, Me. 02172, USA.

35. Kaiser Engineers, Kaiser Centre, 300 Lakeside Drive, Oakland, Calif. 94604, USA.

36. Mandel Scientific Co., Ltd., 4920 De Maisonneuve Blvd., Suite 10, Montreal 215, Quebec, Canada.

37. Millipore Ltd., 55 Montpellier Blvd., Montreal 370, Quebec, Canada.

38. Osmonics, 15404 Industrial Road, Hopkins, Minn.55426, USA.

39. Osmotic Sciences Div. of Greenwood Industries, 468 Prospect Street, Newport Beach, Calif. 92660, USA.

40. Peacock Bros., P.O. Box 1040, Montreal Quebec, Canada.

41. Permutit Co., E49 Midland Avenue, Paramus, N.J. 07652, USA.

42. Pharmacia Co., 110 Place Cremazie, Suite 412, Montreal 351, Quebec, Canada.

43. Philco Ford, Ford Road, Newport Beach, Calif. 92633, USA.

44. Polymetrics, 3011 Corvin Drive, Santa Clara, Calif. 94051, USA.

45. Raypak Inc., 31111 Agoura Road, Westlake Village, Calif. 91361, USA.

46. Raypak Thermonics (Canada) Ltd., 120 Skyway Avenue, Rexdale, Ontario, Canada.

47. Schleicher & Schuell, Keene, N.H. 03431, USA.

48. Selas Corp., Spring House, Penn. 19477, USA.

49. Triton Water Systems, Inc., 15600-01So. Main Street, Gardena, Calif. 90248, USA.

50. Ultradynamics Corporation, 2 Wait Street, Paterson, N.J. 07524, USA.

51. Universal Water Corp., 11722 Sorrento Valley Road, San Diego, Calif., USA.

52. Ultrascience, 2504 Gross Point Road, Evanston, I11. 60201, USA.

53. Vaponics Inc., Cordage Park, Plymouth Mass.02360, USA.

54. Westinghouse Canada Limited, Box 510, Hamilton, Ontario, Canada.

55. Westinghouse Electric Corporation, Power Generation Divisions, Heat Transfer Division, Lester Branch, P.O. Box 9175, Philadelphia, Penn 19113, USA.